FIFTH EDITION

Handbook of VETERINARY ANESTHESIA



William W. Muir, III
John A. E. Hubbell
Richard Bednarski
Phillip Lerche

ELSEVIER

Equivalents of Body Weight in Kilograms and Pounds

kg	lb	kg	lb
0.5	1.1	50	110
1	2.2	55	121
2	4.4	60	132
3	6.6	70	154
4	8.8	80	176
5	11	90	198
6	13.2	100	220
8	17.6	120	264
10	22	140	308
12	26.4	160	352
14	30.8	180	396
16	35.2	200	440
18	39.6	250	550
20	44	300	660
22	48.4	350	770
24	52.8	400	880
26	57.2	450	990
28	61.6	500	1100
30	66	600	1320
35	77	800	1760
40	88	1000	2200

1 kg = 2.2 lb; 1 lb = 0.454 kg.

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The authors wish to dedicate the fifth edition of *Handbook of Veterinary Anesthesia* to all of the veterinary technicians and students who continue to inspire the current and previous editions.

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Preface

This fifth edition of the *Handbook of Veterinary Anesthesia* represents the authors and editors best efforts to update and expand the previous edition and provide essential new information in a format that is readily accessible to veterinarians and technicians needing to immobilize or anesthetize animals. As with any revision, the challenge was to strike a balance between respecting the history of anesthesia and some discontinued anesthetic drugs (halothane and thiopental) while providing original information on new drugs and techniques that have been introduced but, as of yet, have not been widely adopted. We have regrouped chapters to consolidate some topics; expanded chapters on pain and pain management, fluid therapy, and monitoring anesthetized animals; and added chapters on orotracheal intubation, perioperative hypothermia and anesthetic techniques in camelids to increase content and improve the organization and presentation of pertinent information. We continue to focus on providing material that is relevant and "ready to use" for veterinarians and veterinary technicians who treat common domestic species but are sometimes asked to provide care for exotic species and birds. Our goal is to improve anesthesia in veterinary practice and reduce pain and suffering in animals.

This fifth edition is the result of the inspiration, advice, and labors of a number of individuals from the staff and faculties of the Animal Medical Center of New York, New York, the Peak Performance Veterinary Group of Colorado Springs, Colorado, and the Section of Anesthesiology of the Department of Veterinary Clinical Sciences at The Ohio State University and Cornell University. We specifically thank Dr. Turi Aarnes DVM, DACVA, for contributing the chapter "Temperature Regulation During Anesthesia: Anesthetic Associated Hypothermia and Hyperthermia"; Drs. James S. Gaynor, DVM, MS, DACVA, DAAPM, and Leilani Alvarez, DVM, CVA, CCRT, CVCHM, for their comments and contributions to integrative medicine and acupuncture; Dr. Katherine Quesenberry, DVM, MPH, DAVBP, for her review and contribution of figures for anesthetic procedures in exotic animals; and Dr. Luis Campoy, LVCert VA, MRCVS, DECVA, for contributing figures for local anesthesia in dogs and cats. We thank you all for the inspiration to constantly improve anesthesia and pain management, but mostly we thank you for your commitment to improving the quality of life for all animals.

William W. Muir and John A.E. Hubbell

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Introduction to Anesthesia

1

"There are no safe anesthetic agents; there are no safe anesthetic procedures; there are only safe anesthetists."
ROBERT SMITH

OVERVIEW

The applied practice of veterinary anesthesia is based on a general understanding of the following: (1) the terms used to describe the drugs, techniques, and consequences of anesthesia (2) the pharmacology, pharmacokinetics, pharmacodynamics, and toxicology of the drugs used to produce and antagonize anesthesia, (3) the current methods for delivering and assessing the anesthetic drugs' effects, and (4) and appropriate therapy for anesthetic-related complications or emergencies. This chapter defines commonly used terms, outlines general uses for anesthetic drugs, their combinations, and conventional methods used to produce immobilization and anesthesia in animals.

General Considerations

I. Anesthesia's purpose is to produce a convenient, safe, effective, and economical means of facilitating medical and surgical procedures while minimizing stress, pain, discomfort, and adverse side effects to the subject and attending personnel.

II. Criteria for selection of drugs and techniques
- A. Species, breed, age, weight, and body type
- B. Behavior
- C. Physical status and coexisting disease processes
- D. Nature, location, and severity of pain
- E. Current and past medications
- F. Knowledge and experience of personnel (Fig. 1-1)
- G. Familiarity with available equipment and techniques
- H. Duration and type of procedure to be performed

III. Responses vary because drug doses and techniques are initially developed for the "average, normal, healthy" animal; thus, it is essential that drugs, drug dosages, and anesthetic techniques are



FIG. 1-1. A dedicated, knowledgeable, and vigilant anesthetist is key to successful anesthesia.

selected based on the subject's physical status (developed by the American Society of Anesthesiologists: ASA)

A. **Physical Status 1**— A normal healthy patient
B. **Physical Status 2**—A patient with mild systemic disease
C. **Physical Status 3**—A patient with severe systemic disease
D. **Physical Status 4**—A patient with severe systemic disease that is a constant threat to life
E. **Physical Status 5**—A moribund patient who is not expected to survive without the operation

IV. Definitions

A. Medical terms used in the practice of anesthesia: Most definitions of anesthesia incorporate a loss of feeling (analgesia) and/or awareness (unconsciousness). Muscle relaxation and a reduction in the stress response are added benefits.

Acupuncture: The stimulation of specific trigger points based on traditional Chinese medicine

Additive: An effect in which two substances or actions used in combination produce a total effect the same as the sum of the individual effects.

Agonist: A drug that produces an effect by interacting with a specific receptor site (e.g., opioid agonist morphine)

Akinesia: Loss of motor response (movement) usually caused by blockade of motor nerves

Allodynia: Pain evoked by a stimulus that does not normally cause pain
Analeptic: a central nervous system (CNS) stimulant or respiratory stimulant
Analgesia: Loss of sensitivity to pain; relief of pain without loss of consciousness
Anesthesia: Total loss of sensation in a body part or in the whole body, generally induced by a drug or drugs that depress the activity of nervous tissue either locally, regionally, or generally (centrally). The act of producing anesthesia is generally divided into phases that include the preanesthetic, anesthetic, and postanesthetic periods (see box)

The Five Phases of Anesthesia

I. Preanesthetic or preinduction period
II. Induction
III. Maintenance
IV. Recovery
V. Postanesthetic period

Balanced anesthesia: Surgical anesthesia produced by a combination of two or more drugs or anesthetic techniques, each contributing its own pharmacologic effects; includes tranquilizers, opioids, nitrous oxide, muscle relaxants, and inhalants
Dissociative anesthesia: A CNS state characterized by catalepsy, analgesia, and altered consciousness; produced by drugs such as ketamine and tiletamine
General anesthesia: (1) Loss of consciousness in addition to loss of sensation; (2) ideally includes hypnosis, muscle relaxation, analgesia, and suppression of stress; can be produced with a single drug or by a combination of drugs
Local anesthesia: Analgesia generally limited to a specific area where the anesthetic drug is applied or injected
Regional anesthesia: Analgesia limited to a circumscribed region of the body produced by blocking sensory nerves
Surgical anesthesia: Loss of consciousness and sensation accompanied by sufficient muscle relaxation and analgesia to allow surgery to be performed without pain or movement by the animal

Antagonist: a drug that counteracts the effects of another drug (e.g., opioid antagonist naloxone)
Catalepsy: State characterized by a lack of response to external stimuli and by muscular rigidity, so that the limbs remain in whatever position they are placed
Central sensitization: An increase in nerve excitability and responsiveness in the CNS, particularly the spinal cord
Distress: (1) State produced when the biologic cost of stress negatively affects biologic functions critical to the animal's well-being; (2) to cause pain or suffering or to make miserable
Euthanasia: Loss of consciousness and death without causing pain, distress, anxiety, or fear
Homeostasis: A state of equilibrium within the body; a relatively stable equilibrium between interdependent physiological processes
Hyperalgesia: An increased or exaggerated response to a stimulus that is normally painful (a heightened sense of pain) either at the site of injury (primary) or in surrounding undamaged tissue (secondary or extraterritorial). Stimulated nociceptors respond to noxious stimuli more vigorously and at a lower stimulus intensity.
Hypnosis: Artificially induced sleep or a trance resembling sleep from which the animal can be aroused by a sufficient stimulus; animals cannot be aroused during general or surgical anesthesia
MAC (minimum alveolar concentration): (1) A term used to describe the minimum alveolar concentration of inhalant anesthetic required to prevent movement in response to a noxious stimulus in 50% of anesthetized animals; (2) infrequently, in human outpatient anesthetic practice, used to mean monitored anesthesia care
Multimodal therapy: The use of multiple drugs with different mechanisms of action to produce optimal analgesia
Narcosis: Drug-induced stupor or sedation with or without hypnosis
Neuroleptanalgesia: Hypnosis and analgesia produced by the combination of a neuroleptic drug (i.e., tranquilizer) and an analgesic drug
Pain: An aversive sensation and feeling associated with actual or potential tissue damage
Adaptive pain: Pain that produces behavior that promotes healing and recovery

Inflammatory pain: Pain associated with tissue damage and the infiltration of immune cells; it can promote repair by causing pain hypersensitivity until healing occurs

Maladaptive pain: Pain that tends to be out of all proportion to actual tissue damage and which persists long after the tissues have healed so that the pain becomes the problem

Pathologic pain: A disease state caused by damage to the nervous system (neuropathic) or by its abnormal function (dysfunctional). Pathological pain is maladaptive and usually includes peripheral sensitization, central sensitization, and hypersensitivity resulting in allodynia.

Dysfunctional pain is pain caused by abnormal function of the nervous system; often considered to be pain in the absence of disease

Neuropathic pain is caused by damage or disease affecting any part of the nervous system

Physiologic or nociceptive pain: The normal response to a noxious stimulus that produces protective mechanisms causing the animal to minimize tissue damage (fight-or-flight response) or to avoid contact with external stimuli during a reparative phase

Perioperative: around (the time of) surgery; the period of time extending from when the animal enters the hospital for surgery until the time the animal is discharged

Peripheral sensitization: An increase in the activity, excitability, and responsiveness of peripheral nerve terminals

Quality of life: The properties or characteristics that define an animal's life; usually assessed subjectively as a degree of excellence. An individual's ability to exist within the environment to which it is accustomed and to do so in such a way as to not deviate from normal behavioral patterns that define the level of satisfaction of that individual.

Sedation: CNS depression in which the animal is awake but calm and generally uninterested in its surroundings; a term often used interchangeably with tranquilization; sufficient stimulation will arouse the animal

Stress: The biologic responses of an animal to cope with a disruption or threat to homeostasis. A stressor is a physical, chemical, or emotional factor (e.g., pain, trauma, fear) to which an individual fails to make a satisfactory adaptation

and which causes physiologic tensions that may contribute to the development of disease

Synergistic: The combined action of two or more processes (usually drugs) that is greater than the sum of each acting separately

Tranquilization, ataraxia, neurolepsis: State of tranquility and calmness in which the animal is relaxed, reluctant to move, awake, unconcerned with its surroundings, and potentially indifferent to minor pain; sufficient stimulation will arouse the animal

V. Clinical jargon

Bag: "The animal was bagged." The rebreathing bag on the anesthetic machine was squeezed to inflate the animal's lungs during anesthesia

Block: "The leg was blocked." Local anesthesia was produced at a specific site, locally or regionally

Bolus: "A bolus of thiobarbiturate was administered." A specific quantity of drug or fluid was rapidly administered intravenously

Breathed: "The animal was breathed six times a minute." The lungs were either manually or mechanically inflated

Bucking: "The animal is bucking the ventilator." The animal resists assisted or controlled ventilation by attempting to exhale during the inspiratory cycle or inhale during the expiratory cycle.

Crashed: "The animal crashed." The animal demonstrated marked CNS and cardiopulmonary depression after the administration of an anesthetic drug. "The animal was crash induced." Anesthesia was rapidly induced with an IV or inhalant anesthetic drug.

Deep: "The animal is in a deep stage of anesthesia." Anesthetic drugs can produce significant CNS depression. The greater the degree of CNS depression, the deeper the anesthesia. This term is used in direct contrast to the term light, which implies minimal CNS depression. Animals that are "light" demonstrate active corneal, palpebral, and swallowing responses to stimulation; may develop nystagmus; and occasionally lift their head or move a limb.

Down: The animal was "knocked down" or "put down." The animal was given a drug or combination of drugs that produced recumbency. The term put down is also used to denote euthanasia.

Dropped: "The animal was dropped." The animal received drugs that produce recumbency

Extubated: "The animal was extubated." The endotracheal tube was removed from the airway. The term is the opposite of "intubated."
Hit or stick a vein: "I hit the vein on the first attempt." A successful venipuncture was performed
Induced: "The animal was induced." The animal was given a drug or drugs that produced anesthesia
Intubated: "The animal was intubated." An endotracheal tube was placed through the nose or mouth into the trachea
IV drip: "The animal received an IV drip." A fluid with or without added drug(s) was administered intravenously
Mask induced: "The animal was mask induced." A face mask was used to facilitate delivery of inhalant anesthetics for induction of anesthesia
PIVA: The animal was administered PIVA or partial intravenous anesthesia. The use of intravenous anesthetics to augment inhalant anesthetics in order to reduce the dose of the inhalant
Pre or post: "A preanesthetic was administered." Anything administered or done before anesthesia is induced is considered to be in the preanesthetic period. Occurrences after the discontinuation of anesthetic drugs are considered postanesthetic.
Preemptive: "The subject received preemptive analgesia." The deliberate administration of therapy (in this case, analgesia) before the event requiring therapy. A form of prophylaxis
Pushed: "The thiobarbiturate was pushed." IV drug or fluids were administered either rapidly or in amounts greater than usually given
Ran a strip: "I ran a strip on that animal." An electrocardiogram was obtained
Reversed: "The animal was reversed." A drug's effects were antagonized by administering a specific antagonist. For example, the opioid antagonist naloxone can be administered to reverse the effects of morphine.
Spiked: "The animal spiked a fever" or "The fluids were spiked with potassium." Depending on the clinical situation, spiked may mean a sudden rapid increase or that some substance (i.e., K+) or drug was added to a solution
Stabilized: "The animal is stable" or "The animal has been stabilized." Cardiopulmonary variables or the "depth" of anesthesia have been returned to or are within acceptable limits

Stupor: "The animal is in a stupor." A depressed level of consciousness wherein the animal is unresponsive and only responds to aggressive stimulation of pain. The eyes remain open and may follow moving objects.
TIVA: "The animal was administered TIVA" or total IV anesthesia (inhalants were not used)
To Effect: something that is produced by a cause (ex. drug) in order to obtain a desired result
Topped-off: "The animal was topped off with a thiobarbiturate." An additional drug was administered to produce the desired effect. The term implies that the original calculated dose was insufficient to produce the desired effect.
Tubed: "The animal was tubed." An endotracheal tube was placed in the trachea through either the mouth or nasal cavities (see also intubated)
Weaned: "The animal was weaned off the ventilator." The gradual discontinuation of artificial ventilation so that spontaneous ventilation resumes

Use of Anesthetics

I. Immobilization
- A. Physical examination and diagnostic imaging (e.g., ultrasonography, radiography)
- B. Cleaning, grooming, dental prophylaxis
- C. Biopsy, radiation therapy, bandaging, splinting, cast application
- D. Capture of exotic and wild animals
- E. Transportation
- F. Manipulation
  1. Catheterization
  2. Wound care
  3. Obstetrics
- G. Assist or control breathing

II. To produce anesthesia (see Definitions: Anesthesia)
- A. To facilitate or permit medical and/or surgical procedures

III. Control of convulsions
IV. Euthanasia

Effect of Route and Method of Administration of Anesthetic Drugs

I. Intravenous (Figs. 1-2 and 1-3): onset of action is immediate; peak effect is rapidly obtained; duration of action is short; and effects are generally more intense than with other routes

Types of Anesthesia (According to Route of Administration)

Acupuncture	Intraosseous	Oral*
Buccal*	Intraperitoneal	Rectal
Electroanesthesia	Intratesticular	Spinal (subarachnoid)
Epidural*	Intrathoracic	Subcutaneous*
Infiltration*	Intravenous*	Topical*
Inhalation*	Local and regional*	Total body hypothermia
Intramuscular*	Ocular	Transdermal*

*Route commonly used in veterinary medicine

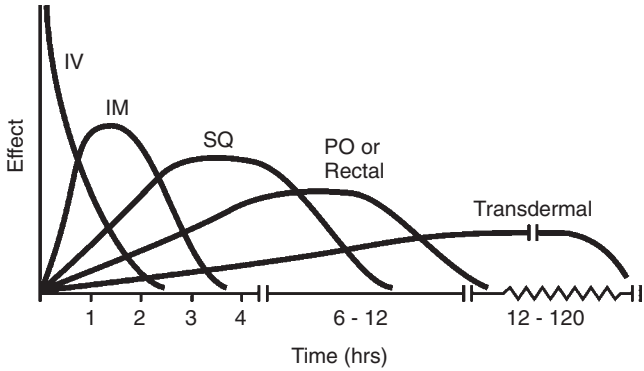


FIG. 1-2. Magnitude of drug effect and duration of action associated with various routes of administration.

II. Given intramuscularly or subcutaneously: onset of action may take 10 to 15 minutes; peak effect may not be obtained for many minutes to hours depending on the animal's body temperature and the blood supply to the tissues at the site of injection, drug absorption, and the rate of metabolism of the drug. The drugs' effects and duration of action are less predictable and more prolonged than by the IV route.

III. Transdermal: peak systemic effects may not occur for many hours

IV. Rapidity of injection: rapid injections generally cause more intense effects, especially true when cardiac output is low

V. Concentrations of solutions

A. Drugs should be administered on a unit per kilogram of body weight (e.g., mg/kg) or unit per body surface area (BSA;

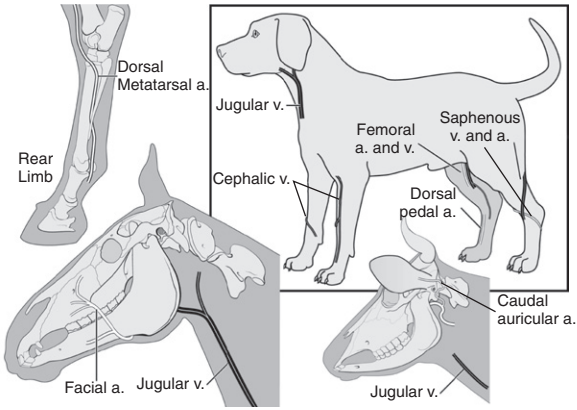


FIG. 1-3. The jugular, cephalic, and saphenous veins are frequently catheterized to administer IV drugs and fluids. The dorsal metatarsal and facial arteries (horses), auricular artery (cattle, sheep, goats, pigs, camelids, cats), dorsal pedal arteries (dogs, cats) and coccygeal artery (cats) are catheterized to monitor direct arterial blood pressure and to obtain arterial blood samples for pH and blood gas (PaO_2, $PaCO_2$) analysis.

e.g., mg/m^2) basis; most drug concentrations are listed as unit per milliliter (e.g., mg/mL) or percent (%); percent solutions can be converted to unit per milliliter (a 1% solution contains 10 mg/mL; therefore a 0.5% solution contains 5 mg/mL, and a 3% solution contains 30 mg/mL)

$$\frac{\text{Body weight (BW) in kg}}{\dfrac{K_m \times BW^{0.67}}{100}} = \text{BSA of cats and dogs}$$

TABLE 1-1 Conversion Factors

Species	To Convert Animal Dose in mg/kg to Dose in mg/m^2, Multiply by K_m
Mouse	3
Hamster	5
Rat	6
Ferret	7
Guinea pig	8
Monkey	12
Rabbit	12
Dog or cat	20
Mini-pig	35

This conversion K_m value is provided for reference only

B. Increasing the drug concentration increases the intensity and duration of the immediate drug effect.
C. Increasing concentrations or rate of drug or fluid administration may increase vascular irritation and cause pain on injection

VI. Amount: the amount (dose: mg/kg) of drug administered should be reduced in sick animals

VII. The onset of action of inhalant drugs depends on alveolar ventilation, cardiac output, and blood flow distribution to the CNS. Absorption of volatile anesthetics and gas from lung (alveoli) into the blood is reduced by dead space ventilation and ventilations-perfusion inequalities

VIII. Duration of drug action is primarily determined by the pharmacokinetic characteristics of the drug (metabolism and elimination), but can be markedly influenced by the duration of drug administration (context-sensitive half-times). Changes in hemodynamics (blood flow distribution) or body temperature (hypothermia) and the total amount of drug administered also influence drug action

2 Animal Evaluation and Preparation

"There is no short cut to achievement. Life requires thorough preparation—veneer isn't worth anything."
GEORGE WASHINGTON CARVER

OVERVIEW

Anesthesia is more than the delivery of anesthetic drugs. Safe anesthesia includes assessing the physical status of the animal, noting the administration of concurrent medications, selecting the appropriate drugs for each procedure, and having a working familiarity with anesthetic drugs, their potential toxicities, and treatment of anesthetic related side effects. This chapter outlines preoperative evaluation as it relates to subsequent anesthetic management.

General Considerations

I. The preanesthetic evaluation (history, physical condition, physical examination) informs the choice and dose of anesthetics to be used for a procedure

II. The history and physical examination are the basis of the evaluation of the animal; the need for further workup is indicated by abnormalities found during physical examination or historical information that suggests altered body function

III. Laboratory tests are not an acceptable substitute for a thorough physical examination

IV. Dosing requirements should be carefully considered and are based on the animal's health, previous drug history (drug interactions are possible), and body condition

A. Drug dosing for emaciated or obese animals should be adjusted downward

B. More ideal dosing is obtained by administering unit doses on the basis of body surface area (mg/m^2) rather than body weight (mg/kg)

Body surface area (BSA) formula for cats and dogs (see Table 1-1)

$$\frac{K_m \times BW^{0.67}}{100} = BSA$$

V. A patent airway must be maintained in every animal
VI. A patent IV route must be maintained for all animals that are at high risk of complications
VII. Anticipate likely untoward events based on history, physical status, and the procedure
VIII. An emergency cart with appropriate resuscitative drugs and antagonists should be maintained (see Chapters 28 and 29)

Evaluating the Animal

I. Animal identification
   A. Case number or animal name
   B. Signalment
      1. Species
      2. Breed
      3. Age (<3 months? >8 years?)
      4. Sex and status (spayed? neutered?)
   C. Body weight
II. Client complaint and anamnesis (history)
   A. Duration and severity of illness
   B. Concurrent symptoms or disease
      1. Diarrhea?
      2. Vomiting?
      3. Hemorrhage?
      4. Seizures?
      5. Heart failure (cough, exercise intolerance?)
      6. Renal failure (change in frequency of urination?)
   C. Level of activity (exercise intolerance?)
   D. Timing of most recent feeding
   E. Previous and current administration of drugs
      1. Organophosphates (insecticides)
      2. Analgesic medications (nonsteroidal antiinflammatory drugs, fentanyl patch)
      3. Heartworm preventatives
      4. Antibiotics
         a. Sulfonamides
         b. Gentamicin, amikacin, polymyxin B
      5. Behavior-modifying drugs (reserpine, chlorpromazine, clomipramine)
      6. Cardiac drugs
         a. Inotropes (digitalis glycosides, phosphodiesterase inhibitors)
         b. β-Blockers (esmolol)

c. Antiarrhythmic drugs (e.g., lidocaine, sotalol)
d. Calcium channel blockers (afterload reducers)
e. ACE (angiotensin converting enzyme) inhibitors or angiotensin blockers (enalapril)

7. Diuretics
8. Anesthetic history and reactions

Current Physical Examination

I. General body condition
A. Body condition score (1 to 5)
1. 1 = Emaciated
2. 2 = Thin
3. 3 = Ideal
4. 4 = Overweight
5. 5 = Obese

B. Pregnancy
C. Hydration (dry mucous membranes? tenting skin?)
D. Temperature (infection? stress? environment?)

II. Cardiovascular
A. Heart rate and mean arterial blood pressure ranges (Table 2-1)
B. Pulse quality and regularity
C. Arterial blood pressure; central venous pressure
D. Capillary refill time (<1.5 seconds) and color (endotoxemia?)
E. Auscultation (cardiac murmurs or increased lung sounds)

III. Pulmonary
A. Respiratory rate, volume, and effort

TABLE 2-1 Normal Heart Rate and Mean Arterial Blood Pressure Ranges

Animal	Heart Rate (beats/min)	Mean Arterial Blood Pressure (mm Hg)
Dog	70-100	70-100
Cat	100-200	80-120
Horse	30-45	70-90
Foal	50-80	60-80
Cow	60-80	90-140
Sheep, goat	60-90	80-110
Pig	60-90	80-110

1. Usually 12 to 25 breaths/min for small animals, 8 to 20 for large animals
2. Tidal volume 10 to 14 mL/kg at rest

B. Mucous membrane color
1. Pallor (anemia or vasoconstriction)
2. Cyanosis (respiratory insufficiency, >5 g/dL of unoxygenated hemoglobin)

C. Auscultation (presence or absence of breath sounds over thorax)
D. Upper airway obstruction (snoring? stridor?)
E. Percussion of thorax (resonant? dull?)

IV. Hepatic
A. Jaundice (yellow buccal membranes)
B. Failure of blood to clot, bruising
C. Coma, seizures

V. Renal
A. Palpate bladder (distended? intact?)
B. Vomiting
C. Oliguria/anuria
D. Polyuria/polydipsia
E. Straining to urinate (urinary obstruction?)

VI. Gastrointestinal
A. Diarrhea or lack of feces
B. Vomiting, regurgitation, or dysphagia
C. Abdominal distention
D. Auscultation of intestinal sounds
E. Condition of teeth and gums
F. Rectal palpation when appropriate

VII. Nervous system and special senses
A. Demeanor
1. Calm or excited
2. Nervous or apprehensive
3. Aggressive or passive

B. Pain
1. Acute or chronic
2. Scoring systems (see Chapter 20)

C. Seizures
D. Fainting
E. Coma
F. Blindness
G. Paralysis or weakness
H. Head tilt

VIII. Metabolic and endocrine
- A. Temperature (hypothermia, hyperthermia)
- B. Hair loss
- C. Hyperthyroidism/hypothyroidism
- D. Hyperadrenocorticism/hypoadrenocorticism
- E. Diabetes (cataracts?)

IX. Integument
- A. Hydration
- B. Neoplasia (pulmonary metastasis)
- C. Subcutaneous emphysema (fractured ribs)
- D. Parasites (fleas, mites); anemia
- E. Hair loss
- F. Burns (fluid and electrolyte loss)
- G. Trauma

X. Musculoskeletal
- A. Muscle mass (% body fat)
- B. Weakness
- C. Electrolyte imbalance (hypokalemia, hyperkalemia; hypocalcemia)
- D. Ambulatory or nonambulatory
- E. Fractures (splinted? unstable?)
- F. Hernias

Preanesthetic Laboratory Workup

I. Minimum laboratory evaluation (Table 2-2)
- A. Plasma protein (oncotic pressure, capacity for fluid administration)
- B. Packed cell volume or hemoglobin (oxygen-carrying capacity)

II. Other laboratory tests if indicated, (Tables 2-2 to 2-5)
- A. Complete blood count (hydration? anemia? infection?)
- B. Blood gases and pH (respiratory insufficiency? shock?)
- C. Hemostasis (bleeding? bruising?)
- D. Albumin (edema? abnormal plasma protein?)

III. Blood chemistry profile (see Table 2-3)
- A. Electrolytes (Na^+, K^+, $C1^-$, Ca^{2+}) (shock? cardiovascular collapse? endocrine disease?)
- B. Blood urea nitrogen (liver disease?)
- C. Creatinine (dehydration? renal disease?)
- D. Aspartate aminotransferase (AST), alanine aminotransferase (ALT) (trauma? liver disease?)
- E. Bile acids (jaundice? liver function?)

TABLE 2-2 Normal Hematologic Values

Parameter	Dog	Cat	Horse	Cow	Sheep	Pig
Plasma protein (g/dL)	5.7-7.2	5.6-7.4	6.5-7.8	7.0-9.0	6.3-7.1	6-7.5
PCV (%)	36-54	25-46	27-44	23-35	30-50	30-48
Hb (g/dL)	11.9-18.4	8.0-14.9	9.7-15.6	8.3-12.3	10-16	10-15
RBCs ($\times 10^{12}$/L)	4.9-8.2	5.3-10.2	5.1-10.0	5.0-7.5	—	—
Total leukocytes ($\times 10^9$/L)	4.1-15.2	4.0-14.5	4.7-10.6	3.0-13.5	4-12	6.5-20
Neutrophils—segmented ($\times 10^9$/L)	3.0-10.4	3.0-9.2	2.4-6.4	0.7-5.1	1-6	3-15
Neutrophils—band ($\times 10^9$/L)	0.0-0.1	0.0-0.1	0.0-0.1	0.0-0.1	0-0.1	0-0.5
Lymphocytes ($\times 10^9$/L)	1.0-4.6	0.9-3.9	1.0-4.9	1.1-8.2	2-8	2-12
Monocytes ($\times 10^9$/L)	0.0-1.2	0.0-0.5	0.0-0.5	0.0-0.6	0-0.6	0-0.6
Eosinophils ($\times 10^9$/L)	0.0-1.3	0.0-1.2	0.0-0.3	0.0-1.5	0-1	0-0.6
Basophils ($\times 10^9$/L)	0.0	0.0-0.2	0.0-0.1	0.0-0.1	0-0.1	0-0.1

Hb, Hemoglobin; *PCV*, packed cell volume; *RBCs*, red blood cells.

IV. Urinalysis (normal findings given in parentheses)
- A. Specific gravity (1.010 to 1.030)
- B. Physiochemical evaluation
  1. pH (7.0 to 7.5, meat diet; 7.0 to 8.0, vegetable diet)
  2. Protein, acetone, bilirubin, blood (negative)
- C. Microscopic evaluation of urine sediment
  1. Casts (absent or rare)
  2. Red blood cells (absent); occasional red blood cells are seen depending on sample collection (cystocentesis?)
  3. White blood cells, epithelial, and bacteria (absent)

Further Preanesthetic Tests

I. Electrocardiography
- A. Traumatized animals (myocardial trauma and arrhythmias)
- B. Bradycardia or irregular cardiac rhythm on physical examination

II. Radiology
- A. Thorax (trauma? metastases?)
- B. Abdomen (distention, foreign body?)

III. Ultrasonography
- A. Cardiac murmurs
- B. Abdominal distention

TABLE 2-3 Serum Chemistry

Parameter	Units	Dog	Cat	Horse	Cow	Sheep	Pig
Calcium	mg/dL	9.3-11.6	8.4-10.1	11.1-13.0	8.6-10.0	8.1-9.5	—
Phosphorus	mg/dL	3.2-8.1	3.2-6.5	1.2-4.8	3.8-7.7	3.5-6.7	5.3-9.6
Glucose	mg/dL	77-126	70-260	83-114	55-81	50-80	60-100
Creatinine	mg/dL	0.6-1.6	0.9-2.1	0.8-1.7	0.7-1.6	—	1.0-2.7
Bilirubin (T)	mg/dL	0.1-0.4	0.1-0.4	0.6-1.8	0.0-0.4	—	—
Bilirubin (D)	mg/dL	0.0-0.1	0.0-0.1	0.1-0.3	0.0-0.0	—	—
Albumin	g/dL	2.9-4.2	2.5-3.5	2.8-3.6	2.7-4.6	2.4-3	—
Total protein	g/dL	5.1-7.1	5.6-7.6	6.4-7.9	6.4-9.5	6.3-7.1	—
BUN	mg/dL	5-20	13-30	13-27	4-31	5-20	8-24
Cholesterol	mg/dL	80-315	65-200	51-97	40-380	—	—
ALP	IU/L	15-120	15-65	80-187	20-80	—	—
Amylase	IU/L	150-1040	400-1300	—	—	—	—
CK	IU/L	50-400	70-550	150-360	90-310	—	—
SDH	IU/L	—	—	4-13	14-80	—	—
AST	IU/L	12-40	10-35	170-370	50-120	—	—
ALT	IU/L	10-55	20-95	—	—	—	—
Na	mEq/L	143-153	146-156	132-142	133-143	140-145	139-152
K	mEq/L	4.2-5.4	3.2-5.5	2.4-4.6	3.9-5.2	4.9-5.7	4.4-6.7
Cl	mEq/L	109-120	114-126	97-105	98-108	—	100-105
Ca^{2+}	mg/dL	5.0-6.1	4.9-5.5	6.0-7.2	4.7-5.4	—	9.5-12.7
Mg	mg/dL	0.53-0.89	0.6-1.0	0.53-0.91	0.6-1.1	—	—
pH	Units	7.27-7.43	7.25-7.33	7.32-7.45	7.32-7.45	—	—
PO_2 (venous)	mm Hg	25-46	31-49	24-39	24-39	—	—
PCO_2 (venous)	mm Hg	28-49	35-49	34-53	34-53	—	—
HCO_3	mEq/L	18-25	18-22	23-31	23-31	—	—
Base excess	mEq/L	-6.0 to 0.5	-6.0 to -3.0	-1.0 to 5.0	-1.0 to 4.2	—	—
Cortisol 0 hr	µg/dL	1.0-11.0	1.0-13.5	2.0-14.0	0.7-1.4	—	—
Cortisol 1 hr post ACTH	µg/dL	5.0-26.0	6.8-12.1	2.7-6.0	2.7-6.0	—	—
T_3 (RIA)	ng/dL	30-130	40-75	20-160	60-190	—	—
T_4 (RIA)	µg/dL	0.5-2.1	1.0-3.0	0.6-2.7	1.7-5.8	—	—

ACTH, Adrenocorticotropic hormone; *ALP*, alkaline phosphatase; *ALT*, alanine aminotransferase; *AST*, aspartate aminotransferase; *BSP*, bromsulphalein; *BU*N, blood urea nitrogen; *CK*, creatine kinase; *LDH*, lactate dehydrogenase; *R*, retention; *SD*H, sorbitol dehydrogenase; *T1/2*, half-life; T_3, triiodothyronine; T_4, thyroxine.

TABLE 2-4 Arterial Blood Gases

Parameter	Normal Values (21% O_2)	Values Routinely Observed During Anesthesia
pH	7.4 ± 0.2	7.30-7.45
$PaCO_2$ mm Hg	40 ± 3	30-60*
PaO_2 mm Hg	94 ± 3	250 to 500 (100% O_2) up to 250 (50% O_2)
Base excess	0 ± 1	–4 to –10

*The development of respiratory acidosis during anesthesia is common; its degree of severity depends in part on the drugs used, the depth of anesthesia, the duration of anesthesia, the species, and animal's status.

Preparing the Animal

I. Withhold food
- A. Withholding food is species and age dependent (see species-specific recommendations)
- B. Do not withhold food for excessive periods in neonates, toy breeds, animals weighing less than 5 kg, or birds

II. Correct or compensate for
- A. Dehydration or hypovolemia (preanesthetic fluids)
- B. Anemia, blood loss, or hypoproteinemia (transfusion)
- C. Acid-base and electrolyte abnormalities (preanesthetic fluids, relieve renal obstruction)
- D. Cardiac dysfunction (diuretics, inotropic drugs)
- E. Respiratory distress (preoxygenation, chest tube placement)
- F. Renal dysfunction (preanesthetic fluids, diuretics, relieve obstruction)
- G. Hemostatic defects (plasma or blood transfusion, desmopressin)
- H. Temperature (heating or cooling)

III. Specific preparation for intended procedure
- A. Thoracic (preoxygenation, ventilator set up)
- B. Abdominal (rapid intubation, extended food withhold?)
- C. Orthopedic (provide analgesia, immobilization?)
- D. Ophthalmologic (neuromuscular blockade?)
- E. Neurologic (control seizures, provide analgesia)

IV. Other considerations
- A. Fluid and caloric needs during and after anesthesia
- B. Special medications (inotropes, antiarrhythmics)
- C. Duration of surgery
- D. Needs of the surgeon

TABLE 2-5 Hemostasis and Temperature

Parameter	Units	Dog	Cat	Horse	Cow	Sheep	Pig
Platelets	$\times 10^9$/L	106-424	150-600	125-310	192-746	250-800	200-700
PT	sec.	6-7.5	8-11.5	8-10	12-18.5	13-17	—
APTT	sec.	9-21	8-17	30-39	24-57	35-50	—
				Normal Body Temperature			
	Fahrenheit (degrees)	101.5-102.5 (small breed)	100-102.5	99.5-101.5 (foal)	101.5-103.5 (calf up to 1 yr)	102-104	102-104 (piglet)
		99.5-101.5 (large breed)		99-100.5 (adult)	100-102.5 (ox)		100-102 (adult)
	Celsius (degrees)	38.5-39.2 (small breed)	37.8-39.2	37.5-38.6 (foal)	38.6-39.8 (calf up to 1 yr)	38.9-4	38.9-40 (piglet)
		37.5-38.6 (large breed)		37.2-38 (adult)	37.8-39.2 (ox over 1 yr)		37.8-38.9 (adult)

APTT, Activated partial thromboplastin time; *PT*, prothrombin time.

Plan for Anesthetic Management

I. Formulating anesthetic care plan
- A. Surgical procedure (special requirements, e.g., controlled ventilation)
- B. Positioning
- C. Selection of drugs: emphasis on pain control during all phases of the preoperative, intraoperative, and postoperative periods
- D. Airway management
- E. Fluid management
- F. Body temperature management (smaller animals, open body cavities)
- G. Monitoring (dependent on species, duration of anesthesia, and procedure)
- H. Anticipation of possible untoward effects and response problems

II. Assembling emergency drugs and equipment (see Chapter 28)

Classifying Physical Status

Class I: Normal animal with no organic disease
Class II: Animal with mild systemic disease
Class III: Animal with severe systemic disease that limits activity but is not incapacitating
Class IV: Animal with incapacitating systemic disease that is a constant threat to life
Class V: Moribund animal not expected to live 24 hours with or without intervention
Designate emergency operation by an "E" after appropriate classification.

Adapted from American Society of Anesthesiologists criteria.

3 Preanesthetic and Perioperative Medications

"No animal should ever be anesthetized without the benefit of preanesthetic medication."
WILLIAM WALLACE MUIR, III

OVERVIEW

Pre and postanesthetic (perianesthetic) medications are essential to safe anesthetic management. When used appropriately, they minimize stress, cardiopulmonary depression, and the deleterious effects produced by IV and inhalant anesthetic administration. Preanesthetic medications almost always reduce the required dose of injectable or inhalant anesthetics and postanesthetic medications improve the quality of recovery.

Preanesthetic medications generally include combinations of drugs from multiple categories: *Anticholinergics* (atropine, glycopyrrolate) limit salivary secretions and emesis and limit or prevent bradycardia, particularly vagally induced bradycardias. *Phenothiazine tranquilizers* (acepromazine) reduce anxiety (anxiolytic), produce calming, and generally enhance the central nervous system (CNS) depressant or analgesic effects of other anesthetic drugs. *Benzodiazepines* (diazepam, midazolam) produce anxiolytic, anticonvulsant, and muscle relaxant effects. α_2-*Agonists* (xylazine, dexmedetomidine) produce sedation, stupor, analgesia, and muscle relaxation without producing general anesthesia. *Opioids* (morphine, butorphanol) produce analgesia; some produce sedation. The combination of an α_2-agonist or tranquilizer with an opioid (neuroleptanalgesia) produces marked calming, muscle relaxation, and analgesia and light stages of anesthesia, especially in young or old animals. Postanesthetic medications are generally administered to hasten or improve recovery and include *Analeptics* (doxapram), CNS stimulants, generally used to stimulate respiration. *Analgesics* can include α_2-agonists, opioid and nonopioid analgesics (meloxicam, tramadol), and specific drug antagonists including but not limited to benzodiazepine (flumazenil), α_2-(atipamazole), opioid (naloxone), and peripheral neuromuscular blocking drug antagonists (neostigmine).

Purposes of Preanesthetic and Postanesthetic Drugs

I. Preanesthetic drugs
  A. Facilitate physical restraint by modifying behavior (Fig. 3-1)



FIG. 3-1. Preanesthetic medication should produce tranquilization or sedation and analgesia and make the animal placid, reluctant to move, and uninterested in its surroundings while reducing the amount of drug(s) required to produce general anesthesia.

1. Animal does not resist physical manipulation
2. Animal is not interested in or is oblivious to surroundings
3. Animal may be reluctant to move

B. Reduce anxiety, fear, and stress
C. Produce muscle relaxation
D. Reduce or prevent pain before, during, and after surgery

E. Decrease the dose of drug required to produce sedation, muscle relaxation, analgesia, or general anesthesia
F. Facilitate safe and uncomplicated induction, maintenance, and recovery
G. Minimize or prevent the adverse and potentially toxic effects of concurrently administered drugs
H. Modulate autonomic reflex activity, whether of sympathetic or parasympathetic origin

II. Postanesthetic drugs
A. Produce an animal that is compliant and pain free
B. Facilitate postoperative care
C. Reduce or prevent pain
D. Minimize or prevent the adverse and potentially toxic effects of concurrently administered drugs
E. Modulate autonomic reflex activity, whether of sympathetic or parasympathetic origin

Drug Categories

I. Anticholinergics (e.g., atropine, glycopyrrolate)
A. Competitively antagonize acetylcholine at sites innervated by postganglionic, parasympathetic (cholinergic) nerve fibers and on smooth muscles that are influenced by acetylcholine but lack innervation; referred to as parasympatholytics, anticholinergics, or antispasmodics
B. Primarily used to limit salivary secretions, prevent bradycardia, or deliberately increase heart rate
C. Inhibit bradycardia caused by reflex increases in vagal tone (e.g., laryngeal or ocular stimulation and vasovagal reflexes)
1. Increasing heart rate generally increases arterial blood pressure (BP) and cardiac output
2. Parasympatholytics may induce a sinus tachycardia or occasionally precipitate ventricular arrhythmias. Anticholinergic drugs may cause sinus bradycardia then progress through first- and second-degree atrioventricular block before the establishment of a faster sinus rhythm (Fig. 3-2).
3. Atropine sulfate may stimulate vagal nuclei in the medulla and, thus, induce an initial sinus bradycardia; not seen with glycopyrrolate
4. Vagal reflexes (bradycardia) produced by traction on visceral organs or during ocular surgery can be but are not always successfully treated with parasympatholytic drugs

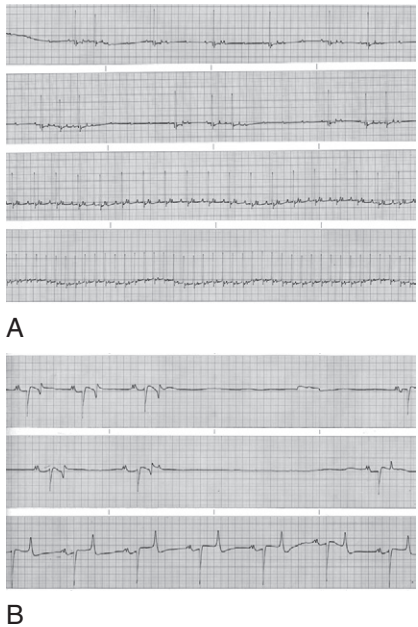


FIG. 3-2. Sinus bradycardia with or without second-degree atrioventricular block (P wave not followed by a QRS) can occur in normal, quiet dogs (A: top 4 traces) and horses (B: bottom 3 traces) and is produced by many drugs (opioids, α_2-agonists). Slow ventricular rates should be avoided. Atropine or glycopyrrolate are generally effective therapy (third and fourth tracings in [A], third tracing in [B]) but should not be administered simultaneously with α_2-agonists unless an emergency condition exists.

5. General anesthetics, opioids, α_2-agonists, digitalis glycosides, hyperkalemia, acidosis, and injection of calcium salts augment vagal effects and may precipitate bradycardia
   a. Opioids and α_2-agonists increase parasympathetic tone and can produce sinus bradycardia and first- and second-degree atrioventricular block
   b. Isoflurane, sevoflurane, and barbiturates indirectly enhance parasympathetic effects by suppressing sympathetic tone
   c. Phenothiazine tranquilizers rarely produce a CNS-induced cholinergic effect and pronounced sinus bradycardia

D. Gastric pH is increased (i.e., less acidic); gastrointestinal (GI) motility and contractions of the bladder and ureters are reduced; intestinal motility can be decreased for several hours

in horses, an effect that could cause colic. Ruminal atony (bloat) can occur in ruminants

E. Reduce glandular secretions of the respiratory tract, GI tract, oral and nasal cavities
   1. The accumulation of excessive secretions in the oral cavity of small animals (e.g., cats) may predispose to upper airway obstruction or trigger laryngospasm
   2. Increased secretory activity may occur after parasympatholytic drug effects subside; this is known as a *postparasympatholytic rebound* phenomenon

F. Produce bronchodilation (increased physiologic dead space) and mydriasis

G. Atropine and scopolamine may produce drowsiness and potentiate the effects of CNS depressant drugs; large doses may stimulate cerebral areas, leading to restlessness, disorientation, and delirium, an effect more common in ruminants and elephants

H. Glycopyrrolate, a quaternary ammonium drug, does not cross the blood-brain or placental barriers

Useful Facts ▪ Anticholinergics

- Competitively antagonize acetylcholine (vagal tone)
- Inhibit bradycardia by decreasing vagal tone; may cause sinus tachycardia
- Reduce glandular secretions; increase gastric pH; decrease GI motility
- Bronchodilation and mydriasis
- Atropine may produce drowsiness
- Glycopyrrolate does not cross the blood-brain or placental barriers

I. Administer intramuscularly (IM) or subcutaneously (SQ) (IV for emergencies)
   1. Atropine (20 to 40 μg/kg) or glycopyrrolate (10 μg/kg) increases heart rate and dries secretions in small animals. The duration of action of atropine is 60 to 90 minutes; the duration of action of glycopyrrolate is 2 to 4 hours.
   2. Parasympatholytics are of questionable value in horses and ruminants because of side effects (bloat, colic) or lack of effect, respectively
      a. Horses: atropine, 20 to 40 μg/kg; glycopyrrolate, 3.3 to 6.6 μg/kg IV in response to bradycardia
      b. Ruminants: not recommended for decreasing salivation; atropine temporarily decreases secretions, which can

become more viscous; proper positioning of the head and neck is of the utmost importance to prevent pooling of saliva in the pharynx and subsequent aspiration

c. Pigs: atropine (20 to 40 μg/kg); glycopyrrolate (3.3 μg/kg)

Doses ▪ Anticholinergics

Agent	Animal	Dose	Duration
Atropine	Small animals	20-40 μg/kg	60-90 min
	Horses	20-40 μg/kg	
	Pigs	20-40 μg/kg	
Glycopyrrolate	Small animals	5-10 μg/kg	2-4 hr
	Horses	3.3-6.6 μg/kg	
	Pigs	3.3 μg/kg	

J. Untoward reactions
1. Atropine may slow heart rate transiently after IV administration
2. Cardiac arrhythmias: first- and second-degree atrioventricular block progressing to sinus tachycardia can be observed after IV administration of atropine or glycopyrrolate in animals with sinus bradycardia; ventricular arrhythmias may occur after IV administration
3. Sinus tachycardia increases myocardial oxygen consumption and can precipitate heart failure or pulmonary edema in animals with preexisting cardiovascular disease (heart failure) if heart rate becomes excessively rapid
4. Atropine may cause CNS depression in dogs and cats; it may cause restlessness, delirium, and disorientation in ruminants and elephants
5. Slows intestinal transit time and is thought to cause ileus and colic in horses

II. Tranquilizers and sedatives (e.g., phenothiazines, butyrophenones, benzodiazepines, α_2-agonists; Table 3-1)

A. Phenothiazines (e.g., acepromazine, promazine), butyrophenones (e.g., droperidol)
1. Mode of action
a. Calming and neurologic effects are mediated by depression of the reticular activating system and antidopaminergic actions in the CNS

TABLE 3-1 Intravenous Doses of Commonly Used Tranquilizers and Sedatives

Agent	Dog	Cat	Horse	Cow	Goat	Pig
MAJOR TRANQUILIZERS						
Acepromazine*	0.05-0.20	0.05-0.20	0.01-0.04	0.01-0.02	0.02-0.04	0.1-0.2
Promazine	2.0-6.0	1-3	0.2-1.0	0.2-1.0	0.2-1.0	1-3
MUSCLE RELAXANTS						
Diazepam	0.2-0.4	0.2-0.4	0.02-0.10	0.4-1.1	0.4-1.1	0.5-2.0
Midazolam	0.2-0.4	0.2-0.4	0.01-0.04	—	—	0.1-0.5
SEDATIVES						
Detomidine	—	—	0.01-0.02	0.01-0.02	—	—
Medetomidine	0.005-0.020	0.01-0.04	0.005-0.020	—	—	—
Dexmedetomidine	0.005-0.020	0.01-0.04	0.005-0.020			0.005-0.020
Romifidine	0.04-0.09	0.09-0.18	0.07-0.12	—	—	
Xylazine	0.4-1.0	0.4-1.0	0.4-1.0	0.02-0.1.0	0.02-0.07	1-2
Chloral hydrate	—	—	60-100	40-70	30-60	40-70

Doses are given as mg/kg.
*The maximum total dose of acepromazine as preanesthetic medication in dogs is 4 mg.

Cautions ▪ Anticholinergics

- Atropine IV may cause an initial bradycardia but is more likely to cause sinus tachycardia
- Atropine or glycopyrrolate IV may cause first- and second-degree atrioventricular block before sinus tachycardia
- Atropine IV may cause ventricular arrhythmias
- Atropine may cause CNS depression in dogs and cats and restlessness or delirium in ruminants
- Atropine may cause colic in horses, bloat in ruminants
- Atropine has the potential to cause increases in intraocular pressure

   b. Suppress the sympathetic nervous system (depress mobilization of catecholamines centrally and peripherally)
   c. Phenothiazine tranquilizers may lower seizure threshold in animals with epilepsy, however, they may inhibit chemically induced seizures (e.g., ketamine)
   d. Phenothiazines and butyrophenones produce antiemetic effects by inhibiting dopamine interaction in the chemoreceptor trigger zone in the medulla
2. Physical properties
   a. Water soluble
   b. Can be mixed with other water-soluble drugs (e.g., acepromazine and hydromorphone; acepromazine and ketamine)
3. Produce mental calming, decrease motor activity, and increase threshold for responding to external stimuli
   a. Not considered analgesic, but improve the analgesic effects of other drugs
   b. Excessive doses of phenothiazines and butyrophenones can cause involuntary (extrapyramidal) musculoskeletal effects and hallucinatory activity in some animals, particularly horses
   c. The calming effect can be temporarily reversed with an adequate stimulus; larger doses may be required in excitable or apprehensive animals and may produce disorientation, ataxia, and attempts to escape
4. Cardiopulmonary effects
   a. α-Adrenergic blockade results in vasodilation and a decrease in arterial BP (hypotension). Subsequent epinephrine administration may cause a paradoxical

Useful Facts ▪ Phenothiazines, Butyrophenones

- Antiarrhythmic effects
- Antiemetic effects
- Antihistaminic effects
- Antisympathetic effects
- Calming and muscle relaxation
- Effective for 4 to 8 hours, residual effects for up to 48 hours
- Metabolized by the liver
- Potentiate analgesics

drop (β_2 effect) in arterial BP because α receptors are blocked.

(1) Hypotension occurs more frequently in excited or apprehensive animals. Reflex tachycardia may occur in response to hypotension. Treat with IV fluids or α-adrenergic agonist (phenylephrine: see below).

(2) Severe reactions include hypotension resulting in fainting and (rarely) bradycardia (reported in Boxer dogs) resulting in death

(3) Phenylephrine (α_1-agonist) and IV fluids can be used to increase BP if hypotension is severe

b. Heart rate usually decreases as the animal becomes calm; however, reflex tachycardia may occur if the animal becomes hypotensive

c. Antiarrhythmic effects: phenothiazines block α_1-receptors, produce quinidine-like effects, and decrease central sympathetic, ganglionic, and peripheral (adrenal) activity, reducing the incidence of ventricular arrhythmias

d. Dose-dependent depression of the myocardium and vascular smooth muscle

5. Reduce respiratory rate; may decrease tidal volume when administered in large doses; decreases respiratory center sensitivity to increases in carbon dioxide (CO_2)
6. Potentiate the ventilatory and cardiovascular depressant effects of α_2-agonists, opioids, and drugs used to produce general anesthesia
7. Useful as antiemetics. Acepromazine and droperidol administered 15 minutes before opioids lower the incidence of vomiting.

8. Most have antihistaminic properties; phenothiazines and butyrophenones should be avoided when skin testing for allergies
9. Most phenothiazine tranquilizers cross the placental barrier relatively slowly
10. Many phenothiazine tranquilizers, including acepromazine and promazine, may cause erection (priapism) and temporary or permanent prolapse of the penis in stallions or geldings. Potentially reversible by administering benztropine (20 μg/kg IV).
11. Butyrophenone tranquilizers produce calming and antiemetic effects (see above)
12. Primary organ of metabolism is the liver; should be avoided in animals with moderate to severe liver disease or portocaval shunts
13. Clinical effects are present for 4 to 8 hours but residual effects may last up to 48 hours or longer in older animals or animals with liver disease
14. Acepromazine is the most popular and safe phenothiazine used in veterinary practice; butyrophenone tranquilizers are rarely used in veterinary medicine (Tables 3-1 and 3-2)
15. Side effects
    a. Tachycardia or (rarely) bradycardia
    b. Hypotension; decreases in BP may result in transient decreases in packed cell volume and plasma total protein
    c. Hypothermia secondary to peripheral vasodilation
    d. Acepromazine significantly decreases platelet numbers and their ability to aggregate; however, this does not

Cautions ▪ Phenothiazines, Butyrophenones

- Hypotension
- Hypothermia
- Inhibit platelet aggregation
- Not considered an analgesic
- Excessive doses of phenothiazines or butyrophenones can cause apparent involuntary musculoskeletal and extrapyramidal effects
- Occasional bradycardia (e.g., boxer dogs)
- Long duration of action (e.g., hepatic shunts)

TABLE 3-2 Intravenous Doses of Commonly Used Opioids and Neuroleptanalgesics

Agent	Dog	Cat	Horse	Cow	Goat	Pig
OPIOID AGONISTS AND PARTIAL AGONISTS						
Morphine	0.4-1.0	0.1-0.2	0.04-0.10	0.04	0.04	0.05-0.1
Meperidine	1-5	0.5-1.0	2-4	2-4	—	0.4-1.0
Hydromorphone	0.1-0.2	0.1	0.02-0.10	—	—	—
Oxymorphone	0.1-0.2	0.1	0.02-0.10	—	—	—
Methadone	0.5-1.0	0.1 (not recommended in cats)	0.05-0.10	—	—	0.1-0.2
Fentanyl	2-6 μg/kg	1-3 μg/kg	0.07-0.15	—	—	—
Pentazocine	0.5-2.0	0.5-1.0 (not recommended in cats)	0.3-0.9	—	—	0.5-2.0
Butorphanol	0.2-0.4	0.2-0.4	0.01-0.02	0.1	0.1	0.1-0.2
Buprenorphine	0.02	0.02	0.01	—	—	—
NEUROLEPTANALGESICS						
Acepromazine-hydromorphone	0.05-0.1 (acepromazine)*; 0.1 (hydromorphone)*					
Acepromazine-oxymorphone	0.05-0.1 (acepromazine)*; 0.1 (oxymorphone)*					
Xylazine-morphine	0.1-0.5 (xylazine); 0.1-0.3 (morphine)					

Doses are given as mg/kg unless otherwise stated.
IM dose is one to two times the IV dose. Lower drug doses should be used in sick animals.
*Dogs and cats only.

produce hemostasis problems in otherwise normal animals. Avoid in animals with von Willebrand's disease or other clotting abnormalities.

e. Akathisia: restless condition in which the patient needs to be in constant motion
f. Acute dystonic reactions: hysteria, seizures, ataxia
g. Tranquilizers alter behavior, generally producing calming and depression but can increase anxiety and produce restlessness and occasionally aggression in some dogs and cats. Their effects on the reticular formation of the pons and medulla (extrapyramidal effects) can lead to akinesia (inability to initiate movement) and akathisia (inability to remain motionless) particularly in aged animals.

B. Benzodiazepines (e.g., diazepam, midazolam, zolazepam) are centrally acting muscle relaxants (see Table 3-1)
   1. Mode of action
      a. Exert many of their pharmacologic effects by enhancing the activity of CNS inhibitory neurotransmitters (gamma-aminobutyric acid [GABA], glycine) by binding to the benzodiazepine site of the $GABA_A$ receptor and opening chloride channels, thereby hyperpolarizing membranes. This effect is produced by combining with CNS benzodiazepine (BZ1, BZ2) receptors. Effects can be antagonized by the benzodiazepine antagonist flumazenil.
      b. Depress the limbic system, thalamus, and hypothalamus (reducing sympathetic output), thereby inducing a mild calming effect and disorientation
      c. Reduce polysynaptic reflex activity, resulting in muscle relaxation and antiseizure effects
      d. Stimulate appetite and pica
   2. Physical properties
      a. Diazepam is formulated in 40% propylene glycol, ethyl alcohol, sodium benzoate, or benzoic acid to solubilize the drug; potentially can produce hypotension, bradycardia, and apnea if administered too rapidly IV
      b. Midazolam and zolazepam are water soluble
      c. Diazepam and midazolam are absorbed through the mucosal membranes in the oral cavity and esophagus and in the stomach. Absorption from the solutions or

Useful Facts ▪ Benzodiazepines

- Enhance the activity of CNS inhibitory neurotransmitters: gamma-aminobutyric acid, glycine; combine with CNS benzodiazepine (BZ) receptors
- Relax muscles
- Antiseizure effects
- Minimal calming effect; may produce apprehension and nervousness in dogs and cats
- Minimal cardiopulmonary effects in dogs, cats, alpacas, and horses
- Stimulate appetite and produce pica
- Midazolam and zolazepam are water soluble
- Antagonized by flumazenil

syrups may be significantly improved by slightly increasing the pH (pH 4-6).

3. Recommended doses produce minimal sedation in normal animals; calming effects are observed in sick, depressed, or debilitated animals
   a. Muscle relaxation
   b. Anticonvulsant
   c. Mild calming
4. Cardiopulmonary effects
   a. Minimal hypotensive effects are observed after IV administration
   b. Bradycardia and hypotension may occur after rapid IV administration
   c. Respiratory rate and tidal volume are minimally affected
   d. Some antiarrhythmic effects are produced as a result of decreases in sympathetic nervous system activity
5. Produce muscle relaxation in animals and reduce muscle spasms and spasticity; effects are additive or synergistic with other drugs used to produce general anesthesia (e.g., barbiturates, propofol)
6. Increase seizure threshold; effect is generally transient unless infused
7. Effects on GI activity undetermined
8. Effect on pregnancy has not been determined
9. Diazepam is eliminated in the urine and feces after being metabolized by the liver; duration of action is 1 to 4 hours
10. Diazepam increases appetite in domestic cats and ruminants (probably in all species)

TABLE 3-3 Benzodiazepine, α_2-, and Opioid Antagonists*

Agent	Dose
BENZODIAZEPINE ANTAGONIST	
Flumazenil	0.01-0.10 IV
α_2-ANTAGONIST	
Yohimbine	0.1-0.3 IV 0.3-0.5 IM
Tolazoline	0.5-5.0 slow IV, IM
Atipamezole	0.05 IV
OPIOID ANTAGONIST	
Naloxone	5-15 μg/kg IV
Nalmefene	0.25-30.0 μg/kg
Naltrexone	0.05-0.10 SQ
Nalorphine	0.05-0.10 IV

Doses are given as mg/kg unless otherwise stated.
*Antagonists are used whenever drug reversal is desired. Analgesia may be reversed also.

11. Dose (see Table 3-1)
12. Side effects
    a. Ataxia, particularly evident in large animal species
    b. Paradoxical increase in anxiety leading to excitement and, potentially, aggression in cats
    c. CNS depression in neonates
    d. Bradycardia and hypotension can occur if administered rapidly IV (diazepam)
13. Antagonists: Benzodiazepine antagonist (e.g., flumazenil: 0.01 to 0.1 mg/kg IV; Table 3-3)

Cautions ▪ Benzodiazepines

- May cause disorientation, excitement, and agitation, particularly in cats
- Diazepam painful if administered IM

C. α_2-Agonists (e.g., xylazine, detomidine, romifidine, medetomidine, dexmedetomidine) (see Table 3-1)
    1. Mode of action
        a. Produce CNS depression by stimulating both presynaptic and postsynaptic α_2-adrenoceptors in the CNS and peripherally; decrease norepinephrine release centrally and peripherally and reduce ascending

nociceptive transmission; net result is a decrease in CNS sympathetic outflow and a decrease in circulating catecholamines and other stress-related substances; the CNS effects of α_2-agonists can be antagonized by α_2-receptor antagonists (e.g., yohimbine, tolazoline, atipamezole)

b. Comparative α receptor selectivity for α_2- versus α_1-receptors

Relative Selectiveness of α_2-Agonists

Drug	α_2:α_1-Selectivity
Clonidine	220:1
Detomidine	260:1
Medetomidine	1620:1
Dexmedetomidine (dextrorotatory S-enantiomer of above)	
Romifidine	340:1
Xylazine	160:1

c. Polysynaptic reflexes are inhibited (centrally acting muscle relaxant), but the neuromuscular junction is not affected

d. Induce a sleeplike state (stupor); some animals, especially horses, may startle and should be approached carefully

e. Disinhibition (aggression) is reported in horses after xylazine and detomidine administration

f. Produce analgesia by stimulating CNS α_2-receptors

g. Effects are additive and may be synergistic when combined with other depressants and analgesic drugs (e.g., opioids) used to produce chemical restraint or general anesthesia

2. General properties

a. Produce sedation, muscle relaxation, analgesia, and stress reduction

(1) Detomidine: 90 to 120 minutes IV

(2) Dexmedetomidine: 45 to 90 minutes IV

(3) Medetomidine: 45 to 90 minutes IV

(4) Romifidine: 45 to 90 minutes IV

(5) Xylazine: 20 to 40 minutes IV

b. Can be administered on the buccal mucosa (detomidine is most effective). Also, can be administered epidurally

Useful Facts ▪ α_2-Agonists

- Pronounced sedation
- Muscle relaxation
- Analgesia
- Anxiolysis
- Can be used buccally or by epidural or subarachnoid administration
- Antagonized by α_2-receptor antagonists: yohimbine, tolazoline, atipamezole

or subarachnoidally to produce regional or segmental analgesia.

3. Cardiopulmonary effects
   a. Decreased heart rate caused by decreased CNS sympathetic outflow and increased parasympathetic activity; may initiate sinus bradycardia, first- or second-degree atrioventricular block. Complete (third-degree) atrioventricular block with escape beats is uncommon. Ventricular bradycardia or tachycardia may occur following pronounced sinus bradycardia or sinus arrest.
   b. Xylazine produces increased cardiac sensitivity to catecholamine-induced arrhythmias during halothane anesthesia; this effect occurs early, is transient, and is caused by α_1- and possibly α_2-adrenoceptor stimulation; this effect coincides with increases in arterial BP and is not observed after detomidine, medetomidine, dexmedetomidine, or romifidine administration
   c. Cardiac output may decrease by 30% to 50% and coincides with decreases in heart rate and increases in peripheral vascular resistance
   d. Arterial BP increases shortly after drug administration (α_1- and α_2-adrenoceptor stimulatory effect increasing peripheral vascular resistance); the effect is transient with xylazine but more prolonged with the other drugs
   e. Initial vasoconstriction may cause pale mucous membranes and difficulty placing IV catheters
   f. Depress respiratory centers centrally, resulting in hypoventilation or apnea
   g. Decrease respiratory center sensitivity to increases in PCO_2; decrease tidal volume and respiratory rate with an overall decrease in minute volume when administered in large doses IV. Hypoventilation

produces increases in $PaCO_2$ and end-tidal (ET) CO_2 (ET CO_2).
   h. Respiratory threshold to CO_2 increases, resulting in signs of respiratory depression
   i. May induce stridor and dyspnea in brachycephalic animals and horses with upper airway obstruction
4. Other organ systems
   a. Suppress salivation, gastric secretions, and GI motility; may stimulate pica (abnormal craving) and appetite at low doses
   b. Initiate vomiting in dogs and cats; repeated or prolonged use decreases GI motility and delays gastric emptying and predisposes to bloat in large-breed dogs and horses
   c. Depress swallowing reflex
   d. Excellent for treating GI pain (colic), GI effects decrease GI motility and mask the severity of disease, thereby delaying surgery
   e. Suppress insulin release by stimulating presynaptic α_2-receptors in the pancreas, resulting in an increase in plasma glucose concentration and glucosuria
   f. Promote diuresis with increases in water and sodium excretion by inhibiting anti-diuretic hormone release and increased release of atrial natriuretic factor
5. Absorption, fate, and excretion
   a. Rapidly absorbed after IM, SQ, or sublingual administration
   b. Relatively rapidly metabolized by the liver and excreted in the urine
   c. Active metabolites possible; more than 20 have been identified
6. Other
   a. Produce profound effects in puppies, kittens, foals, and small ruminants
   b. Cross the placenta, but an abortifacient effect has not been noted in pregnant dogs, cats, or mares; no observable effects on gestation or parturition; xylazine may induce premature delivery in cattle. Oxytocin-like in ruminants; this activity has not been reported in dogs, cats, or mares.
   c. Highly excited or nervous animals may react adversely by becoming extremely ataxic, reacting violently or

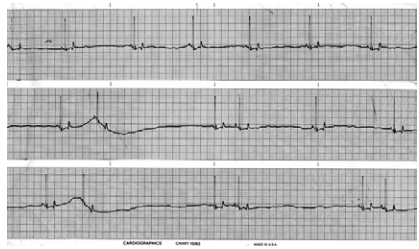


FIG. 3-3. α_2-Agonists (medetomidine, dexmedetomidine) can produce profound sinus bradycardia. Decreases in heart rate decrease cardiac output (CO) because heart rate × stroke volume = CO.

viciously when approached or touched, or showing inadequate response

d. Clinical value of xylazine in pigs is transient because of rapid metabolism; dexmedetomidine (20 to 40 μg/kg) and romifidine are alternatives

7. Side effects
   a. Bradyarrhythmias (Fig. 3-3)
   b. Hypotension (long-term effect)
   c. Decreased tissue perfusion
   d. Respiratory depression (respiratory acidosis)
   e. Vomiting
   f. Ataxia
   g. Diuresis
   h. Sweating in horses
   i. Occasional unpredictable effects; startle, aggression, and increased response to loud noise
   j. Xylazine can produce an inflammatory response if administered SQ in horses or cattle
8. α_2-Antagonists (see Table 3-3)
   a. Yohimbine (0.1 to 0.3 mg/kg IV, 0.3 to 0.5 mg/kg IM)
   b. Tolazoline (0.5 to 5 mg/kg slow IV)
   c. Atipamezole (0.2 mg/kg IV)
   d. Doxapram HCl (0.1 to 0.4 mg/kg): a respiratory stimulant and analeptic; Doxapram is not a specific α_2-antagonist; does reverse respiratory depression and mild sedation

D. Opioids (see Table 3-2)
   1. Mode of action
      a. Act by reversible combination with one or more specific receptors (e.g., μ,κ) in the brain and spinal

Cautions ▪ α_2-Agonists

- Sinus bradycardia, first- or second-degree atrioventricular block
- Xylazine may transiently increase cardiac sensitivity to catecholamine-induced arrhythmias (ventricular arrhythmias) in dogs. Not observed with other α_2-agonists.
- Decrease cardiac output (and tissue perfusion), increase peripheral vascular resistance
- Ileus and bloat in dogs; colic in horses
- Pale mucous membrane caused by vasoconstriction
- Respiratory depression
- Ataxia
- Vomiting in dogs and cats
- Suppress insulin release
- Diuresis
- Oxytocin-like effects in ruminants

Opioid Classifications

- Full opioid agonist: bind to one or more types of opioid receptor and causes certain effects (e.g., morphine)
- Agonists-antagonists: cause some effects of an agonist and possess some properties of an antagonist (e.g., butorphanol). Low doses of butorphanol are additive with full opioid agonists but it is an antagonist at high doses.
- Partial agonist: cause less pronounced effects (partial efficacy relative to a full agonist); (e.g., buprenorphine). When a full agonist and partial agonist are administered, the partial agonist acts as a competitive antagonist.
- Antagonist: binds to one or more types of receptor but causes no effect at those receptors. By competitively (competitive antagonist) displacing an agonist from a receptor, the antagonist effectively "reverses" the agonist's effect (e.g., naloxone).

cord producing a variety of effects including analgesia, sedation, euphoria, dysphoria, and excitement

2. Collectively referred to as opioid agonists, partial agonists, agonist-antagonists, and antagonists
   a. Opioids are represented by a variety of naturally occurring (opiate) derivatives and synthetically manufactured drugs
   b. Classified according to their opioid receptor activity, analgesic activity, or addiction potential
   c. Commonly used opioid agonists include morphine, methadone, meperidine, hydromorphone, oxymorphone, and fentanyl

d. Opioid agonist-antagonists (pentazocine, butorphanol) and partial agonists (buprenorphine) generally produce less sedation than full agonists (e.g., morphine)

Relative Analgesic Potency

Morphine: 1
Methadone: 1
Meperidine: 0.5
Hydromorphone: 7
Oxymorphone: 5 to 10
Fentanyl: 100
Remifentanil: 50
Butorphanol: 0.5 to 3
Buprenorphine: 25

3. Several senses are not significantly depressed by opioids
   a. Touch
   b. Vibration
   c. Vision
   d. Hearing
   e. Smell
4. Often administered before (preemptive), during (adjunctive), or after (rescue analgesia) surgery for analgesia. Fentanyl, sufentanil, hydromorphone, and oxymorphone are generally administered during surgery as part of a balanced anesthetic technique.
   a. Fentanyl patches are applied to provide analgesia before or after surgery. The fentanyl patch is a transdermal drug delivery system. Doses for dogs and cats are 2 to 5 μg/kg/hr; patch sizes are 12.5, 25, 50, 75, or 100 μg/hr. Peak effects are seen 8-12 hours after placement.
   b. Preservation-free morphine (Astramorph) can be administered epidurally or subarachnoidally to produce regional or segmental analgesia
5. The ability to produce analgesia is dependent upon the severity of pain. Some animals do not exhibit analgesia following opioid administration. Larger doses of opioids can produce anxiety, restlessness, agitation, and dysphoria in some animals, especially cats and horses.

6. Effects in addition to analgesia
   a. Behavioral changes (e.g., sedation, euphoria, restlessness, excitement, dysphoria; animal may not recognize owner)
   b. Increased response to external stimuli (e.g., sound)
   c. Miosis in dogs and pigs; mydriasis in cats and horses
   d. Decrease in body temperature in dogs caused by resetting of the thermoregulatory center and panting in dogs
   e. Hyperthermia in cats; mechanism is uncertain
   f. Sweating, particularly in horses
   g. Vomiting, constipation, and urine retention
7. Generally administered in combination with tranquilizers or sedatives (neuroleptanalgesia), or as an adjunct to IV or inhalant anesthesia to produce balanced anesthesia (Tables 3-2 and 3-4). Sedation in dogs but may cause excitement when given rapidly IV; cats and horses are particularly susceptible to the excitatory effect of opioids; this is typified by hyperactivity and dysphoria in cats and increased locomotor activity and pacing in horses. These effects can be controlled by tranquilization (acepromazine) or the administration of an α_2-agonist.
8. Cardiopulmonary effects
   a. Bradycardia caused by stimulation of medullary vagal nuclei. Doses that cause excitement (cats, horses) produce tachycardia.
   b. Possible hypotension caused by opioids that release histamine (morphine, meperidine)
   c. Minimal cardiac inotropic effect at low doses

Useful Facts ▪ Opioids

- Produce analgesia without loss of proprioception or consciousness
- Produce sedation in dogs, but restlessness and excitement as dose increases, especially in cats and horses
- Metabolized by the liver and eliminated in the urine
- Controlled substances (opioid use is strictly controlled)

   d. Respiratory depression (rate and tidal volume) is dose-dependent and uncommon unless the patient is already depressed, unconscious, or suffering from head injury; raises the threshold of the respiratory center to increases in PCO_2

TABLE 3-4 Commonly Used Analgesic and Tranquilizer Combinations for Intravenous Use*

Animal	Drugs	Recommended IV doses	Untoward Effects
Dog	Acepromazine-meperidine	0.1-0.2 (acepromazine) 0.1-0.2 (meperidine)	Hypotension
	Acepromazine-hydromorphone	0.1-0.2 (acepromazine); 0.1-0.2 (hydromorphone)	Hypotension
	Acepromazine-oxymorphone	0.1-0.2 (acepromazine); 0.1-0.2 (oxymorphone)	Hypotension
	Acepromazine-butorphanol	0.1-0.2 (acepromazine); 0.2-0.4 (butorphanol)	Bradycardia Hypotension
	Diazepam-fentanyl	0.2-0.4 (diazepam); 0.01 (fentanyl)	Bradycardia
	Butorphanol-dexmedetomidine	0.2-0.4 (butorphanol); 0.005-0.01 (dexmedetomidine)	Bradycardia
Cat	Acepromazine-hydromorphone	0.2 (acepromazine IM); 0.05 (hydromorphone)	Excitement
	Acepromazine-oxymorphone	0.2 (acepromazine IM); 0.05 (oxymorphone)	Excitement
	Acepromazine-butorphanol	0.1 (acepromazine); 0.2-0.4 (butorphanol)	Bradycardia (acepromazine); Hypotension(butorphanol)
Horse	Xylazine-morphine†	0.6 (xylazine); 0.2-0.6 (morphine)	Bradycardia (xylazine); Hypotension (morphine)
	Xylazine-meperidine	0.6 (xylazine) 0.6 (meperidine)	Hypotension
	Xylazine-butorphanol	0.6 (xylazine); 0.02 (butorphanol)	Ataxia
	Xylazine-acepromazine	0.6 (xylazine); 0.05 (acepromazine)	Hypotension
	Meperidine-acepromazine	0.5 (meperidine); 0.02-0.05 (acepromazine)	Hypotension
Ruminants			
Cow	Xylazine	0.04-0.1	Respiratory depression, bradycardia
Sheep	Xylazine	0.1-0.2	
Goat‡	Xylazine	0.01-0.1*	

Doses are given as mg/kg.
*Lower doses should be used in sick animals.
†Detomidine (10 to 420 μg/kg IV) can be substituted for xylazine in horses; dexmedetomidine (5 to 20 μg/kg IV) or romifidine (0.02 to 0.09 mg/kg IV) can be substituted for xylazine in dogs and cats.
‡Variable response

9. GI effects
   a. Salivation
   b. Nausea and vomiting in dogs and cats
   c. Nonpropulsive GI hypermotility ("ropy guts"), increases in sphincter tone
   d. Initial defecation followed by constipation
10. Urine retention and decreases in urine production due to antidiuretic hormone (ADH) release
11. Cross the placental barrier relatively slowly; useful for cesarean section
12. Rapid absorption; can be given by IV, IM, SQ, oral (buccal), transdermal (fentanyl patches [Fig. 3-4]), or rectal routes. Wide distribution; low bioavailability after oral or rectal administration because of high first-pass effect. Extensively metabolized by the liver, and metabolites are eliminated in the urine. The opioid agonists vary in biologic half-life; most have durations of action ranging from 30 minutes to 3 hours. Most opioids, particularly buprenorphine, demonstrate good bioavailability when administered buccally.
13. Tolerance develops with continued use



FIG. 3-4. Some drugs are administered transcutaneously (ex., fentanyl) or buccally (ex., buprenorphine). Fentanyl is an opioid analgesic that can be absorbed through the skin. A fentanyl patch can be placed on the lateral thorax of dogs or cats. Buprenorphine (dogs, cats, ferrets) and detomidine can be administered buccally.

14. Opioid antagonists (see Table 3-3)
    a. Mechanism of action
        (1) Opioid antagonists compete with opioid agonists and partial agonists for specific opioid receptor sites but do not activate the receptors. They block opioid receptors, preventing them from responding to opiates and endogenous endorphins.
        (2) Partial antagonists act in a fashion similar to opioid antagonists but are generally less potent than full agonists
        (3) Some opioid antagonists (nalorphine, nalmefene) produce species-dependent autonomic, endocrine, analgesic, and respiratory depressant effects
        (4) May potentiate the respiratory depressant effects of anesthetics
    b. Metabolized in the liver
    c. Dose (see Table 3-3)
        (1) Naloxone: 5 to 15 μg/kg IV
        (2) Nalmefene: 0.25 to 30 μg/kg IV
        (3) Naltrexone: 0.05 to 0.1 mg/kg SQ
        (4) Nalorphine: 0.05 to 0.1 mg/kg IV
15. Side effects
    a. Bradycardia
    b. Potential respiratory depression
    c. Vomiting
    d. Excitement, dysphoria

Caution ▪ Opioids

- Bradycardia
- Histamine release (morphine, meperidine); not hydromorphone
- Respiratory depression in animals with CNS depression or head trauma
- Vomiting
- Defecation followed by constipation
- Urine retention
- Tolerance can occur
- Dose-dependent, opioid-induced neuroexcitation

E. Neuroleptanalgesia
    1. A state of CNS depression and analgesia produced by the combination of a tranquilizer or sedative and analgesic drug; useful in dogs, cats, horses, and pigs (see Definitions,

Chapter 1); Dogs and cats may or may not remain conscious and are somewhat responsive to auditory stimuli; many small animals defecate, some vomit. Horses become stuporous and attain a "saw-horse" stance.

2. Neuroleptanalgesic effects
   a. Sedation-analgesia, ataxia, and recumbency in dogs and cats; stupor in large animals (horses)
   b. Respiratory depression (apnea may occur)
   c. Bradycardia
   d. Defecation and flatulence
3. Overdose usually results in profound bradycardia and respiratory depression; respiratory depression can generally be reversed by administration of an opioid antagonist (e.g., naloxone)
4. Neuroleptanalgesics can be administered in conjunction with propofol in dogs and cats to eliminate the stimulatory effect of loud noises and produce better muscle relaxation
   a. Propofol (1 to 3 mg/kg) after diazepam-hydromorphone

Principal Points ▪ Neuroleptanalgesics

- Hypnosis and analgesia
- May or may not remain conscious
- Useful as preanesthetic medication and for short, simple operative procedures and cesarean section

5. Opioids and tranquilizer drug combinations
   a. Acepromazine (0.05 to 0.2 mg/kg) in combination with morphine (0.4 to 0.8 mg/kg IV or SQ), meperidine (1 to 2 mg/kg IV or SQ), hydromorphone (0.1 to 0.2 mg/kg IV or SQ), or oxymorphone (0.1 to 0.2 mg/kg IV or SQ) are used to produce neuroleptanalgesia in dogs; diazepam or midazolam (0.2 mg/kg IV) and hydromorphone (0.1 to 0.2 mg/kg IV or SQ) or oxymorphone (0.1 to 0.2 mg/kg IV or SQ), acepromazine (0.05 to 0.2 mg/kg IM), and butorphanol (0.2 to 0.4 mg/kg IV or IM) are used in dogs and cats
   b. α_2-Agonists (xylazine, medetomidine, dexmedetomidine) combined with opioids (morphine, hydromorphone, butorphanol, buprenorphine) and/or dissociative anesthetics (ketamine) are also used to produce neuroleptanalgesia in dogs and cats

(1) Medetomidine (4 to 20 μg/kg) or dexmedetomidine (2 to 10 μg/kg IM combined with morphine (0.2 mg/kg IM) or other opioids in dogs
(2) Morphine (0.2 mg/kg), medetomidine (60 μg/kg), and ketamine (5 mg/kg) IM for short, simple surgical procedures in cats
(3) Dexmedetomidine dosages usually range from 5 to 10 μg/kg IV; 15-40 μg/kg IM
(4) Dexmedetomidine-butorphanol-ketamine ("Kitty Magic") drug combination for short surgical procedures in cats: 10 to 30 μg/kg dexmedetomidine with 0.2 to 0.6 mg/kg butorphanol and 100 to 300 μg/kg ketamine IM produces heavy sedation to anesthesia (for ovariohysterectomy, onychectomy, abdominal procedures) in cats
(5) The combination of xylazine (0.6 mg/kg IV) or detomidine (20 to 60 μg/kg IV) and morphine (0.2 to 0.4 mg/kg IV) or butorphanol (0.02 to 0.04 mg/kg IV—lower in horses) is commonly administered for dental and standing analgesia in horses

6. Useful for short medical or surgical procedures
7. Side effects
   a. Respiratory depression
   b. Bradycardia
   c. Ataxia
   d. Excitement

Caution ▪ Neuroleptanalgesics

- Bradycardia
- Respiratory depression

Treating Emergencies ▪ Neuroleptanalgesics

- Administer an opioid antagonist (naloxone) and an α_2-antagonist (atipamezole)

F. Other perianesthetic drugs (Tables 3-5 and 3-6)
   1. Nonanesthetic, perianesthetic medications include a spectrum of drugs that are used to minimize or prevent

TABLE 3-5 Nonsteroidal Antiinflammatory Drugs and Doses

Drug	Dose (mg/kg) Dogs	Cats	Horses	Ruminants	Routes	Dose Interval (hr)	Approved Indications	Precaution and Comments
SALICYLATES								
Aspirin	10-35	10-15			PO	8-12 (dogs) 48-72 (cats)		Gastrointestinal side effects (ulcers, hemorrhage); renal failure
				100	PO	12		
PROPIONIC ACIDS								
Carprofen*	4.4				PO (SID)	SID		Pain and inflammation associated with osteoarthritis and pain associated with soft tissue or orthopedic surgery
	2.2				PO (BID)	BID		
	4.4				SQ			
		2			SQ, PO	12 (dogs) 40 (cats)		
			0.05-1.10		IV	24		
Ketoprofen	0.5-2.2	0.5-2.2			IM (dogs), SQ, PO	24; approximately 2 days (cats)		Gastrointestinal side effects (ulcers, hemorrhage); renal failure
			1.1-2.2		IV	24		
				2	IV	12		

Etodolac*	10-15	Not used			PO	24 (SID)	Pain and inflammation associated with osteoarthritis	Safety not evaluated in dogs 12 months of age or younger, dogs used for breeding, or pregnant or lactating bitches
FENAMATES								
Flunixin meglumine	0.25-1	Not used			IV, IM	24; do not repeat		
			0.2-1.1		IV	24		
				1	IV	12		
Meclofenamic acid	1-2	Not used			PO	24		
PYRAZOLES								
Phenylbutazone	10-22 (maximum 800 mg/day)	4-20			IV, PO	8-12 (dogs); 24-48 (cats)		
			2-4		IV	24		
			2-4		PO	12		
				5	PO	24		
Tepoxalin*	Loading: 10 or 20; maintenance: 10	Not used			PO	SID	Pain and inflammation associated with osteoarthritis	Not evaluated in dogs 6 months of age or younger, dogs used for breeding, or pregnant or lactating bitches

Continued

TABLE 3-5 Nonsteroidal Antiinflammatory Drugs and Doses—cont'd

Drug	Dose (mg/kg)				Routes	Dose Interval (hr)	Approved Indications	Precaution and Comments
	Dogs	Cats	Horses	Ruminants				
OXICAMS								
Piroxicam	0.2-0.4	Not used			PO	48		
Meloxicam*†	Loading: 0.2; maintenance: 0.1	Preoperative: 0.3			Loading: IV or SQ; maintenance: PO	SID SID	Pain and inflammation associated with osteoarthritis	Not evaluated in dogs 6 months of age or younger, dogs used for breeding, or pregnant or lactating bitches
	Loading: 0.2; maintenance: 0.1	Loading: 0.2; maintenance: 0.1			SQ, PO	24 (dogs) 11-21 (cats)		
COXIBS								
Deracoxib*	Osteoarthritis: 1-2	Not used			PO	SID	Pain and inflammation associated with osteoarthritis and postoperative pain and inflammation associated with orthopedic surgery	Safety not evaluated in dogs 4 months of age or younger, dogs used for breeding, or pregnant or lactating bitches

	Postoperative: 3-4		PO	SID (7-day limit)		
Firocoxib*	2-5	Not used	PO	SID	Pain and inflammation associated with osteoarthritis	Safety not evaluated in dogs 10 weeks of age and younger, dogs used for breeding, or pregnant or lactating bitches
Robenacoxib†	0.5-1.0	1.0 (PO) (<6 days) 2.0 (SC) × 1	PO	SID	Pain; postoperative pain and inflammation	Similar to other coxibs
PHENACETIN DERIVATIVES						
Acetaminophen	10-15		PO	8-12		Liver failure

*Nonsteroidal antiinflammatory drug approved for use in dogs in North America.
†Nonsteroidal antiinflammatory drug approved for use (preoperative only) in cats in North America.

TABLE 3-6 Non-Anesthetic Drugs Used in the Perioperative Period

Drug	Dose: mg/kg	Considerations
Nonsteroidal Antiinflammatory Drugs (NSAIDs)	**See: Text, NSAIDS Caution and Table 3-5**	**See: Text, NSAIDS Caution and Table 3-5**
Antiemetics		
Metoclopramide	Dogs 0.5 PO, TID Cats 0.2 PO, TID	Avoid in animals with GI obstruction
Maropitant	Dogs 1.0 IV Cats: undetermined	Potential analgesic effects
H_2 Antagonists		
Cimetidine		
Ranitidine	Dogs & Cats 1-2 PO, BID	Somnolence, depression
Famotidine	Dogs & Cats 0.5-1.0 PO, BID	
Proton Pump Inhibitors		
Omeprazole	Dogs & Cats 0.5-0.7 PO, SID	Somnolence, depression
H_1 Antagonists		
Diphenhydramine	Dogs & Cats 0.5-2.0 IV, IM	Somnolence, depression
Glucocorticosteroids		
Dexamethasone	Dogs 0.5-2 SC, IV, IM Cats 0.125-0.5 SC, IV, IM	Avoid in animals with infections, heart failure, diabetes or administered **NSAIDs**

anesthesia-associated side effects or to improve the anesthetic experience generally by providing analgesic or antiinflammatory effects

a. Nonsteroidal antiinflammatory drugs (NSAIDs) (Table 3-5)
b. Antiemetics
c. Histamine (H_1 and H_2) antagonists
d. Proton pump inhibitors
e. Glucocorticoids

2. NSAIDs: NSAIDs are frequently administered before or after anesthesia to reduce inflammation and pain. Several NSAIDs have been demonstrated to decrease the requirement for inhalation anesthesia, although the clinical relevance of this effect is questionable.
   a. Minimal acute side effects following single administration

Principal Points ▪ NSAIDS

- Analgesia
- Antiinflammatory
- Antipyretic
- Inhibition of cyclooxygenase (COX) and prevent prostaglandin synthesis

NSAIDS ▪ Caution

- Do not administer to animals with GI ulceration
- Do not administer to animals with renal disease
- Do not administer to hypovolemic or hypotensive animals
- Do not administer to animals with significant pulmonary disease
- Do not administer to animals that have been administered a glucocorticoid

b. Toxicity associated with GI ulceration and renal failure
c. Phenylbutazone is used in horses (Primarily COX-1 selective)
   (1) Used to treat pain and for a variety of musculoskeletal inflammatory conditions
   (2) Potentially toxic in dogs, cats, and horses (especially foals) (gastric ulceration, renal necrosis, anemia)
d. Flunixin meglumine
   (1) Used in horses (PO, IV). Irritating when administered IM
   (2) Not COX-2 selective
   (3) Used for musculoskeletal conditions and mild colic
   (4) Counteracts the effects of absorbed endotoxins
   (5) Toxic in dogs and cats (single dose occasionally used for ocular inflammation)
e. Carprofen
   (1) Used in dogs (PO, SQ)
   (2) COX-2 selective in dogs
   (3) Indicated for chronic arthritis and mild perioperative pain
   (4) Liver toxicity reported in some Labrador retrievers (resolves with drug withdrawal)
f. Ketoprofen
   (1) Approved for use in horses (IV)
   (2) Used in dogs and cats (IV, IM, SQ) for perioperative analgesic

g. Meloxicam
   (1) Used in dogs and cats (PO, IV, SQ; only SQ in cats)
   (2) COX-2 selective in dogs
   (3) Indicated for chronic arthritis and mild perioperative pain in dogs
   (4) Administration only once before surgery is approved in cats in the United States
h. Deracoxib
   (1) Used for dogs and cats (PO)
   (2) COX-2 selective
   (3) Used for musculoskeletal conditions
i. Firocoxib
   (1) Used for dogs, cats, and horses (PO)
   (2) COX-2 specific
   (3) Used for musculoskeletal conditions

3. Antiemetics are administered to reduce the potential of postoperative nausea and vomiting (PONV) and thereby limit regurgitation and the potential for aspiration pneumonia.
   a. Metoclopramide is an antiemetic and prokinetic that is believed to produce its effects by blocking dopamine (D_2) receptors in the chemoreceptor trigger zone in the CNS. Blockade of serotonin ($5\text{-}HT_3$) receptors may also contribute to antiemetic effects. Prokinetic drugs promote gastric emptying, thereby reducing the amount of gastric fluid that can be refluxed, and increasing lower esophageal sphincter tone, thereby decreasing gastroesophageal reflux
      (1) Metoclopramide is used as an antiemetic to limit nausea and vomiting. It may help to limit or prevent gastroesophageal reflux disease (GERD) and facilitates gastric emptying.
      (2) Metoclopramide dose:
         (a) Dogs: 0.5 mg/kg PO, three times daily (TID)
         (b) Cats: 0.2 mg/kg PO, TID
      (3) Side effects are uncommon with short term administration but may include depression, hyperactivity, or disorientation (cats)
         (a) Metoclopramide may increase the CNS depressant effects of tranquilizers, sedatives, opioids, α_2-agonists, and anesthetics

(4) Do not administer metoclopramide to dogs or cats with GI obstruction, a history of seizures, or pheochromocytoma

b. Maropitant is a neurokinin (NK_1) receptor antagonist, which was developed specifically for the treatment of motion sickness and vomiting in dogs. The efficacy of maropitant for reducing PONV in dogs and cats requires substantiation. Several studies in dogs suggest that maropitant lowers inhalant anesthetic requirements in dogs due to visceral analgesic effects. The clinical relevance of this effect has not been determined.
   (1) Maropitant dose:
      (a) Dogs 1.0 mg/kg; 1 hr before anesthesia; 4 mg/kg to reduce inhalant anesthetic requirements
      (b) Cats: undetermined but likely similar to dogs
   (2) Side effects include excessive drooling, lethargy, lack of appetite, and diarrhea.

4. H_2 antagonists are a class of drugs that block the action of histamine on the parietal cells in the stomach, decreasing acid production
   a. H_2 antagonists may decrease gastric acidity and gastroesophageal reflux, thereby decreasing inflammation and tissue (gastric, esophagus, larynx, pharynx, trachea) damage-associated, visualized or "silent" regurgitation and regurgitation with aspiration
      (1) Dogs and cats with mast cell tumors are occasionally treated with H_2 antagonists because these tumors can produce large amounts of histamine
   b. Cimetidine, ranitidine, and famotidine are H_2 antagonists used in dogs and cats. Cimetidine also inhibits liver enzyme (P450) activity, and it is no longer recommended. Ranitidine and famotidine are much less likely to alter liver enzyme function and are preferred. Dosages for dogs or cats:
      (1) Ranitidine: 1 to 2 mg/kg PO, twice daily (BID)
      (2) Famotidine: 0.5 to 1.0 mg/kg PO BID
   c. Side effects are rare but include depression, allergic reactions (itching, diarrhea), and appetite loss
5. Proton pump inhibitors reduce gastric acid production by irreversibly blocking the hydrogen/potassium adenosine

triphosphatase (ATPase) "proton pump," thereby decreasing acid (H^+) secretion into the stomach
   a. Proton pump inhibitors are used to increase gastric pH, limiting tissue damage associated with gastric inflammation and ulcers, GERD, and regurgitation or aspiration
   b. Omeprazole is the most popular proton pump inhibitor in veterinary medicine. Dosages for dogs or cats:
      (1) Omeprazole: 0.5 to 0.7 mg/kg PO, once daily (SID)
   c. Side effects are similar to H_2 antagonists: depression, allergic reactions (itching, diarrhea), and appetite loss
6. H_1 antagonists or antihistamines compete with histamine at histamine receptors, decreasing the effects of allergens, which are increased vascular permeability, inflammation, and pain
   a. Antihistamines competitively antagonize the effects of histamine at H_1 receptors and are administered for relief from insect bites and allergic reactions and are recommended treatment before surgical resection of mast cell tumors
   b. Diphenhydramine is the most popular antihistamine used in conjunction with anesthesia and surgery before mast cell tumor resection in dogs or cats. Diphenhydramine is also used as an antiemetic and to prevent motion sickness in dogs
      (1) Diphenhydramine: 0.5 to 2.0 mg/kg BID IV, IM
   c. Side effects include sedation, urinary retention, diarrhea, vomiting, and appetite loss. Sedation is not adequate for anesthetic purposes.
      (1) Older dogs and cats may be more susceptible to sedative effects
      (2) Diphenhydramine should be administered with caution to animals with a history of seizures
7. Glucocorticoids are occasionally administered preoperatively to decrease tissue inflammation and pain
   a. Glucocorticoids produce antiinflammatory and analgesic effects by binding to glucocorticoid receptors, which upregulates the expression of antiinflammatory proteins in the cell nucleus and decreases the expression of proinflammatory proteins in the cytosol
   b. Dexamethasone is used to manage immune-mediated diseases such as immune-mediated hemolytic anemia or

thrombocytopenia, cancers, allergic reactions including "asthma" in cats, and inflammatory diseases
   (1) Dogs: 2 to 5 years of age: 0.5 to 1 mg, SC, IM, or IV; 6 to 12 years: 1 to 2 mg, SC, IM, or IV; 12 years (and older): 2 to 4 mg SC, IM, or IV
   (2) Cats: 1 to 9 years of age: 0.125 to 0.500 mg, SC, IM, or IV; 9 years (and older): 0.5 to 1.0 mg, SC, IM, or IV

c. Side effects are uncommon with single or short-term use and concerns regarding infection and delayed healing, although possible, are often exaggerated. Regardless, glucocorticoids should not be administered preoperatively to animals that will be administered nonsteroidal antiinflammatory drugs (NSAIDs) or that have suppressed immune function with a history of gastroenteritis or bacterial or viral infections.
   (1) Gastrointestinal ulcers may occur if administered in conjunction with NSAIDs
   (2) Dexamethasone should not be administered to animals with diabetes or heart failure

4 Local Anesthetic Drugs and Techniques

"And don't give me any of those local anesthetics. Get me the imported stuff."
FROM THE CARTOON "HERMAN" UNIVERSAL PRESS SYNDICATE

OVERVIEW

Local anesthetics produce desensitization and analgesia of skin surfaces (topical anesthesia), tissues (infiltration and field blocks), and regional structures (conduction anesthesia, intravenous regional anesthesia). Local anesthetic techniques are an alternative or adjunct to intravenous and inhalant anesthesia. A number of anesthetic drugs are available; they vary in potency, toxicity, and cost. The most commonly used local anesthetic drugs are lidocaine, mepivacaine, and bupivacaine. Vasoconstrictors (epinephrine) are occasionally added to lidocaine to increase the intensity of effect and prolong anesthetic activity. Adding hyaluronidase increases tissue penetration in the region of infiltration and hastens the onset of analgesic activity.

I. Reasons for producing local/regional anesthesia:
- A. Provide effective preemptive (preventative) and multimodal analgesia
- B. Reduce the amount of inhalant or injectable drug needed to maintain anesthesia
- C. Decrease the stress response to surgical trauma
- D. Reduce the potential for the development of central sensitization

General Considerations

I. Use sterile solutions, equipment, and techniques
II. Avoid injection into inflamed areas (if possible)
III. Use as small a gauge of needle as practical
IV. Aspirate for blood before injecting
V. Use lowest effective concentration of local anesthetic drug to produce the desired effect
VI. Wait for onset of analgesia before proceeding

Local Anesthetics

I. Mechanism of membrane and impulse conduction
- A. Local anesthetics are membrane-stabilizing agents
- B. The drugs enter and occupy (by polar association) the membrane channels through which sodium (Na^+) ions normally move
- C. The most immediate and apparent effect is the prevention of the inflow of Na^+ blocking subsequent ionic flow
- D. Nerve cell depolarization is prevented, thus retarding or stopping the conduction of nerve impulses

II. Uptake
- A. The salt of the local anesthetic base is an ionizable quaternary amine with little or no anesthetic properties of its own
  1. Local anesthetics are formulated as salts because salts are water soluble
  2. Salts are not lipid soluble
  3. Salts are not absorbed into the nerve cell membrane
- B. Once the salt of the anesthetic base is deposited into tissues, it dissociates, and the anesthetic base (B) is liberated as follows:

$$\underset{\text{Salt}}{BH^+Cl^-} \leftrightarrows \underset{\text{anion}}{Cl^-} + \underset{\text{cation}}{BH^+} \leftrightarrows \underset{\text{base}}{B} + H^+ + Cl^-$$

- C. The free anesthetic base is absorbed at the outer lipid nerve membrane. The anesthetic base combines with a hydrogen ion inside the nerve cell and blocks Na^+ channels (Fig. 4-1).
- D. Effect of tissue pH; the acid ionization constant (pK_a) values of local anesthetics are usually between 8 and 9 (except for benzocaine: 2.9)
  1. Local anesthetics are more ionized (more poorly absorbed) in tissues that are more acidic (lower pH)
  2. Infected or inflamed tissues are more acidic and lack buffering capacity; smaller amounts of the free base are produced, resulting in poor local anesthesia

III. Absorption
- A. Local anesthetics are poorly absorbed through intact skin
- B. Local anesthetics are absorbed from:
  1. Mucous membranes
  2. Serosal surfaces
  3. Respiratory epithelium
  4. Intramuscular deposition

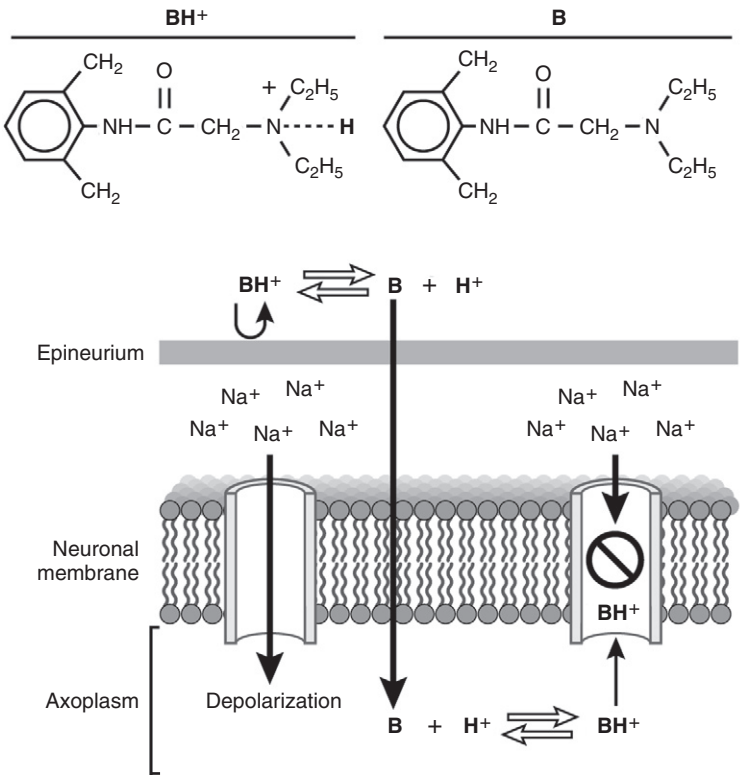


FIG. 4-1. The uncharged (un-ionized) local anesthetic (**B**) is absorbed across the nerve cell membrane, is subsequently ionized blocking sodium channels, thereby preventing membrane depolarization and producing local anesthetic effects. Increases in tissue acidosis (decreased tissue pH) decrease local anesthetic effect.

5. Subcutaneous deposition
6. Injured skin

IV. Classification and function of nerve fibers (Table 4-1)

A. Myelinated A-fibers
   1. α (Alpha): motor, proprioception
   2. β (Beta): motor, touch
   3. γ (Gamma): muscle spindles
   4. δ (Delta): pain, temperature

B. Myelinated B-fibers: preganglionic sympathetic

C. Nonmyelinated C-fibers transmit
   1. Pain, temperature
   2. Postganglionic sympathetic

TABLE 4-1 Classification of Nerve Fibers

Fiber Name	Anatomic Location	Fiber Type and Diameter	Function	Sensitivity to Block
A-FIBERS		**MYELINATED**		
Aα	Efferent and afferent to muscles and joints	6-22 μm	Motor, proprioception	+
Aβ	Efferent and afferent to muscles and joints	6-22 μm	Motor, touch, proprioception	++
Aγ	Efferent to muscle spindle	3-6 μm	Pain, temperature, muscle tone	++
Aδ	Sensory roots	1-4 μm	Pain, temperature, muscle tone	+++
B-FIBERS	Preganglionic sympathetic	<3 μm myelinated	Vasomotor, visceromotor	++++
C-FIBERS	Postganglionic sympathetic, sensory roots	0.4-1.2 μm nonmyelinated	Vasomotor, visceromotor, pain, temperature, touch	++++

V. Sensitivity to local anesthetic effects (least resistant to most resistant)
- A. C-fibers >Aδ-fibers > Aα-fibers
- B. Sensation disappears in the following order: pain, cold, warmth, touch, joint, deep pressure
- C. Motor function can be maintained after all sensation is lost

VI. Blocking quality
- A. Potency is related to lipid solubility: local anesthetics with high lipid solubility have more potent effects
- B. Latency is the time between injection and the peak effect
- C. Duration of action
  1. Binding affinity to receptor protein; local anesthetics with greater protein-binding ability have a longer duration of action; can bind to the receptors in Na^+ channel reliably (bupivacaine, ropivacaine > tetracaine > lidocaine > procaine)
  2. Doubling the concentration of local anesthetic increases the duration of analgesia by approximately 30% (proportional to the logarithm of the concentration)
- D. Recovery time is the time it takes for normal sensation to return

1. Dependent on outflow diffusion and gradual release of local anesthetic from the nerve membrane
2. It may be 2 to 200 times longer than the onset time

VII. Ampules of hydrochloride salts can be autoclaved at 120°C for 20 to 30 minutes without affecting potency

Drugs Used for Vasoconstriction

I. Effects of vasoconstriction
- A. Vasoconstrictors delay absorption, reducing toxicity and increasing the margin of safety
- B. Vasoconstrictors increase intensity and prolong anesthetic activity (up to five times)
- C. Use of vasoconstrictors may cause disturbances of the circulation (e.g., toes, penis, ears)
- D. Vasoconstrictors can increase risk of cardiac arrhythmias and ventricular fibrillation
- E. Dose: epinephrine 5μg/mL (1:200,000)

Drugs Used To Hasten the Time of Anesthesia Onset

I. Hyaluronidase
- A. Increases tissue penetration (may double), resulting in a larger total area being desensitized
- B. Often produces a rapid onset of analgesia
- C. Usually shortens anesthesia time because of increased absorption, unless a vasoconstrictor is also used
- D. May enhance systemic absorption and toxicity
- E. Is not a substitute for precise, accurate technique; fascial planes are barriers to diffusion
- F. Dose: use five turbidity-reducing units per milliliter of local anesthetic solution

Specific Local Anesthetic Drugs

I. Ester-linked drugs (Table 4-2)
- A. Cocaine
- B. Procaine
  1. Prototype of all local anesthetics
  2. Standard drug for comparison of anesthetic effects
  3. Hydrolyzed in plasma by pseudocholinesterase
  4. Less potency and shorter duration than most local anesthetics but minimal toxicity
  5. Not recommended for topical administration because of poor absorption

TABLE 4-2 Local Anesthetics

Agent (Generic Name)	Trade Name (Registered by)	Chemical Name	Potency Ratio (Procaine = 1)
ESTERS			
Procaine	Novocain (Winthrop Stearns)	Para-aminobenzoic acid ester of dimethylaminoethanol	1:1
Tetracaine	Pontocaine (Sanofi)	Para-butylamino benzoyl- dimethylaminoethanol-HCl	12:1
Benzocaine + Butamben + Tetracaine	Cetacaine (Cetylite Industries)	Ethyl 4-aminobenzoate (benzocaine) 4-aminobenzoic acid butyl (butamben)	
AMIDES			
Lidocaine	Xylocaine (AstraZeneca)	Diethylaminoacet-2,6 xylidide	2:1
Mepivacaine	Carbocaine (Winthrop Laboratories)	1-methyl-2′,6′-pipecoloxylidide monohydrochloride	2.5:1
Bupivacaine	Marcaine (Breon Laboratories)	1-butyl-2′,6′-pipecoloxylidide-HCl	8:1
Ropivacaine	Naropin (AstraZeneca)	S-(-)-1-propyl-2′,6′-pipecoloxylidide-HCL monohydrate	8:1
Lidocaine + Prilocaine	EMLA cream (AstraZeneca)	Propylamine-2-methyl- propionanilide hydrochloride (prilocaine)	

Continued

TABLE 4-2 Local Anesthetics—cont'd

Drug	Toxicity Ratio (Procaine = 1)	Dose (%)	Stability	Comment
ESTERS				
Procaine	1:1	1-2 for infiltration and nerve block	Aqueous solutions are heat resistant, decomposed by bacteria	Hydrolyzed by liver and plasma esterase
Tetracaine	10:1	0.1 for infiltration and nerve block; topically 0.2	Crystals and solutions should not be autoclaved	Slow onset of anesthesia (5-10 min); 2 hr duration; for eye instillation
Benzocaine + Butamben + Tetracaine			Keep away from flames, high temperature, alkali or alkaline earth metals, oxidizing agents	Never use for injection; rapid onset (30 sec); 30-60 min duration; may cause methemoglobinemia (mostly cats)
AMIDES				
Lidocaine	0.5% 1:1 1% 1.4:1 2% 1.5:1	0.5-2.0 for infiltration and nerve block; topically 2-4	Aqueous solutions are thermostable; multiple autoclaving possible	Excellent penetrability; rate of onset twice as fast as procaine; 2 hr duration with epinephrine
Mepivacaine	Less toxic than lidocaine	1-2 for infiltration and nerve block	Resistant to acid and alkaline hydrolysis; can autoclave multiple times	Absence of vasodilator effects makes addition of a vasoconstrictor unnecessary
Bupivacaine	Greater margin of safety than lidocaine	0.25 for infiltration; 0.5 for nerve block; 0.75 for epidural block	Stable compound	Intermediate onset, lasting 4-6 hr
Ropivacaine	Greater margin of safety than bupivacaine	0.2 for infiltration; 0.5 for nerve block; 0.75 and 1.0 for epidural block	Stable compound	Intermediate onset, lasting 4-6 hr
Lidocaine + Prilocaine		(Do not spread out; apply a thick layer of medicine)		Possibility of skin trouble, deterioration of methemoglobinemia

C. Tetracaine
1. More potent than procaine (10 to 15 times)
2. Longer duration than procaine (1.5 to 2 times)
3. Relatively toxic
4. Prolonged anesthetic effect
5. Hydrolyzed by pseudocholinesterase
6. Useful for topical anesthesia

D. Benzocaine (Cetacaine)
1. Benzocaine blocks Na^+ channels with pressure caused by membrane expansion, not by a direct inhibition of the channel
2. pK_a: 2.9 (benzocaine), 2.5 (butamben)
3. Rapid onset (approximately 30 seconds) and short duration (approximately 30 to 60 minutes)
4. Use on larynx or pharynx may cause methemoglobinemia in cats
5. Metabolized by plasma cholinesterase
6. Used for surface anesthesia
7. Localized allergic reactions may occur (e.g., erythema, pruritus)

II. Amide-linked drugs

A. Lidocaine
1. Most stable drug in this group; not decomposed by boiling, acids, or alkali
2. Superior penetration compared with procaine**:** fast onset (effects are evident in one-third the time); effects persist 1.5 times longer; spread over a wider field
3. Minimal tissue damage or irritation
4. No allergy or hypersensitivity
5. Mild sedative effects when administered intravenously (IV) (anesthetic sparing)
6. Antiarrhythmic
7. Gastrointestinal promotility effects when administered IV
8. Antiinflammatory effects
9. Antishock effects but potentially can induce hypotension when administered IV
10. Metabolized in the liver
11. Can be infused IV continuously with inhalant anesthesia to augment analgesia

B. Mepivacaine
1. Similar to lidocaine

2. Less irritation or tissue damage
3. Metabolized in the liver

C. Bupivacaine
1. Longer time to onset of analgesic effects than lidocaine
2. Anesthetic effect is longer than procaine (3 to 10 hours)
3. Metabolized in the liver
4. May produce central nervous system and cardiac toxicity

D. Ropivacaine
1. Duration similar to bupivacaine with faster onset
2. Less cardiotoxic than bupivacaine

Topical Anesthetics

I. Commonly used topical anesthetics
A. Butacaine
B. Tetracaine
C. Piperocaine
D. Proparacaine (Ophthaine)
E. Benzocaine/butamben/tetracaine (Cetacaine)
F. EMLA Cream (lidocaine and prilocaine mixture)

II. Vascular effect: local anesthetic drugs are local and occasionally systemic vasodilators, with the exception of cocaine (a vasoconstrictor)

III. Toxicity (Table 4-3) dependent on:
A. Rate of absorption
B. Rate of metabolism

Methods of Local Anesthetic Application (Table 4-4)

I. Surface anesthesia
A. Sprayed or brushed on mucous membranes (mouth, nose, larynx)
B. Dropped into the eye
C. Infused into the urethra

TABLE 4-3 Toxic Reactions of Local Anesthetics

SYSTEMIC
Cardiovascular (hypotension, arrhythmia)
Central nervous system (seizures)
Methemoglobinemia (benzocaine, prilocaine)
Respiratory (apnea)
LOCALIZED OR SYSTEMIC
Allergic reaction (procaine)

TABLE 4-4 Several Methods of Administering Local Anesthetic Drugs

Technique	Clinical Use
Infiltration anesthesia	For lacerations; biopsies; surgical incisions
Splash block	For specific site—local topical analgesia
Digital nerve block	For digit surgery or removal
Intravenous regional nerve block (Bier block)	To repair or perform surgery on a distal limb
Intermittent or continuous (pain buster soaker) local anesthetic delivery	To provide analgesia after accidental or surgical trauma

D. Injected subsynovially (synovial membranes)
E. Injected intrapleurally

II. Infiltration anesthesia
A. Diffuse infiltration of operative area
1. Sensitive tissues: skin, nerve trunks, blood vessels, periosteum, synovial membranes, mucous membranes near orifices (mouth, nose, rectum, anus)
a. Ultrasound-guided techniques have been developed for most species and greatly facilitate the production of specific nerve blocks while reducing the total amount of drug administered and therefore the potential for drug related toxicity
2. Insensitive tissues: subcutis, fat, muscles, tendons, fascia, bone, cartilage, visceral peritoneum
B. Infiltration techniques
1. Bleb (very localized deposition of a small quantity SQ)
2. Tissue layer by tissue layer
C. Uses
1. Minimizing or preventing pain
2. Facilitate surgery
a. Skin incision
b. Surgical removal of superficial tumors
c. Wound repair

III. Regional (perineural) anesthesia
A. Linear block
B. Field block
C. Peripheral nerve block
D. Paravertebral block
E. Nerve block: injection in neuroplexus, ganglia, nerve trunks

F. Epidural block
G. Spinal anesthesia: injection in subarachnoid space

IV. Intraarticular anesthesia
V. Subsynovial anesthesia
VI. Intravenous regional anesthesia
VII. Refrigeration or hypothermic anesthesia

Analgesic Activity of Epidurally and Spinally Administered α_2-Adrenoceptor Agonists

α_2-Adrenoceptor agonists such as clonidine, xylazine, detomidine, medetomidine, dexmedetomidine, and romifidine are used for their sedative, analgesic, anxiolytic, anesthetic sparing, and hemodynamic stability properties; xylazine, detomidine, medetomidine, or romifidine injected epidurally in cattle and horses can produce caudal (S3 to coccyx) localized analgesia with minimal impairment of motor function

NOTE: Opioids and ketamine are also administered epidurally to enhance analgesic activity

I. Site of action
A. The antinociceptive effects of epidurally and intrathecally (subarachnoid) administered α_2-adrenoceptor agonists are primarily the result of:
1. Stimulation of α_2-adrenoceptors in the spinal cord inhibits the release of norepinephrine, hyperpolarizing dorsal horn neurons and inhibiting substance P (a pain-related neurotransmitter) release, thereby producing analgesia
2. Inhibition of impulse conduction in primary afferent nerve fibers; C-fibers (pain, reflex responses, and postsympathetic transmission) are blocked to a greater extent than A-fibers (somatic motor function and proprioception)

B. The antinociceptive effects of epidurally and intrathecally (subarachnoid) administered α_2-adrenoceptor agonists are independent of opioid receptor mechanisms
C. Adding xylazine to an epidural solution containing lidocaine prolongs the duration of analgesia

II. Epidural α_2 agonists (xylazine, detomidine, medetomidine, dexmedetomidine) Note: xylazine is discussed; however, newer α_2 agonists are becoming popular in combination with local anesthetics (bupivacaine or ropivacaine) and opioids (morphine) for epidural administration in dogs and cats

A. Xylazine is the most commonly used α_1-and α_2-agonist for epidural injection in cattle, horses, and pigs (Table 4-5); medetomidine and dexmedetomidine can be administered epidurally in dogs and cats
   1. Xylazine has a high affinity and selectivity for α_1- and α_2- receptors

TABLE 4-5 Epidural Analgesia: Xylazine-, Xylazine/Lidocaine-, Detomidine-, Medetomidine-, Dexmedetomidine-, Morphine-, Detomidine/Morphine-, And Ketamine-Induced Analgesia In Cattle, Goat, Pony, Horse, Pig, Llama, Dog, And Cat

Species	Agonist	Dose (mg/kg)	Volume of Diluent (mL)
Cattle	Xylazine	0.05	5 mL of 0.9% NaCl
	Medetomidine	15 μg/kg	5 mL with sterile water
Goat	Xylazine	0.15	5 mL with sterile water
	Medetomidine	20 μg/kg	5 mL with sterile water
Pony	Xylazine	0.35	—
Horse	Xylazine	0.17	6 mL/450 kg with sterile water
	Xylazine	0.17	5 mL/450 kg with 2% lidocaine (0.22 mg/kg)
	Xylazine	0.25-0.35	8 mL of 0.9% NaCl or 6 mL/450 kg
	Xylazine + Lidocaine	0.17 0.22	6 mL/454 kg with sterile water
	Detomidine	0.06	10 mL/500 kg with sterile water
	Morphine	0.05	10 mL/450 kg with 0.9% NaCl
	Morphine + Detomidine	0.2 0.03	8 mL/450 kg with 0.9% NaCl
	Ketamine	2	10 mL/450 kg with 0.9% NaCl
Pig	Xylazine	2	5 mL of 0.9% NaCl
	Xylazine	1 in large sows >180 kg 2 in small pigs <50 kg	10 mL of 2% lidocaine
	Detomidine	0.5	5 mL of 0.9% NaCl
Llama	Xylazine	0.17	2 mL/150 kg of sterile water
	Xylazine	0.17	1.7 mL/150 kg with 2% lidocaine (0.22 mg/kg)
Dog	Medetomidine Dexmedetomidine	15 μg/kg	0.1 mL/kg with 0.9% NaCl
Cat	Medetomidine Dexmedetomidine	10 μ/kg	1 mL of 0.9% NaCl

Continued

TABLE 4-5 Epidural Analgesia: Xylazine-, Xylazine/Lidocaine-, Detomidine-, Medetomidine-, Dexmedetomidine-, Morphine-, Detomidine/Morphine-, And Ketamine-Induced Analgesia In Cattle, Goat, Pony, Horse, Pig, Llama, Dog, And Cat—cont'd

			Analgesia		
Species	**Site of Injection**	**Spread of Analgesia**	**Onset (min)**	**Duration (min)**	**Side Effects**
Cattle	$C_0$1-$C_0$2	S3 to coccyx	10	>120	Sedation, ataxia, cardiopulmonary depression, ruminal hypomotility diuresis
	$C_0$1-$C_0$2	Tail, perineum, pelvic limbs	5-10	00	Mild-moderate sedation, moderate ataxia, salivation, diuresis, occasional recumbency
Goat	Lumbosacral	Flank, perineum, forelimbs, head	5	>180	Marked sedation, variable cardiopulmonary depression, lateral recumbency
	Lumbosacral	Perineum, thorax, forelimbs, neck, head	3-6	40	Sedation, cardiopulmonary depression recumbency
Pony	$C_0$1-$C_0$2	S3 to coccyx	20-30	240	Mild ataxia
Horse	S5-$C_0$1	S3 to coccyx	30	200	—
	S5-$C_0$1	S3 to coccyx	5	300	Mild ataxia
	$C_0$1-$C_0$2	S3 to coccyx	13	160-180	Minimal cardiovascular and respiratory depression, head ptosis
	$C_0$1-$C_0$2	Tail, perineum	20	240	Mild transient ataxia
	S5-$C_0$1	Bilateral cauda	5	300	Mild sedation, sweating

TABLE 4-5 Epidural Analgesia: Xylazine-, Xylazine/Lidocaine-, Detomidine-, Medetomidine-, Dexmedetomidine-, Morphine-, Detomidine/Morphine-, And Ketamine-Induced Analgesia In Cattle, Goat, Pony, Horse, Pig, Llama, Dog, And Cat—cont'd

			Analgesia		
Species	**Site of Injection**	**Spread of Analgesia**	**Onset (min)**	**Duration (min)**	**Side Effects**
	$C_0$1-$C_0$2	S3-T15 to coccyx	10-15	130-150	Sedation, ataxia, cardiopulmonary depression, diuresis
	$C_0$1-$C_0$2	S3 to coccyx	20	180	—
	$C_0$1-$C_0$2	S3 to coccyx	<5	330	Mild sedation, occasional recumbency
	$C_0$1-$C_0$2	Lumbosacral	20-480	480-780	Mild sedation, hypotension, occasional urticaria
Pig	L6-S1 (via catheter)	Entire pelvic limbs	60	>360	Marked sedation, mild ataxia, bradycardia, bradypnea
	Midsacral (S2-S3), via catheter	Tail, perineum, upper pelvic limbs	5-15	80	Mild sedation, mild ataxia
	Lumbosacral	Umbilicus to coccyx	5	>120	Sedation, immobilization
Llama	Lumbosacral	Umbilicus to coccyx	5-10	300-480	—
	Lumbosacral	Umbilicus to coccyx	10	<30	Atipamezole (0.2 mg/kg IV) reverses sedation
Dog	Lumbosacral	—	—	7 hr.	Bradycardia, increase in blood pressure
Cat	Lumbosacral	Hindlimbs, forelimbs	15	Forelimbs: 120 Hindlimbs: 240	Sedation, emesis

Doses are given as mg/kg unless otherwise stated.

2. Xylazine has local anesthetic properties that are independent of α-adrenergic stimulation

B. Clinical use of epidural xylazine
   1. Cattle: xylazine (0.05 mg/kg of body weight expanded to a 5 mL volume with sterile saline solution) given in the epidural space at the first coccygeal intervertebral or the sacrococcygeal space produces anesthesia in the anal and perineal region for surgery and obstetric procedures (see Table 4-5)
      a. Xylazine-induced caudal epidural anesthesia in cattle is associated with these side effects:
         (1) Marked sedation (head drop)
         (2) Mild ataxia
         (3) Bradycardia
         (4) Hypotension
         (5) Respiratory depression and subsequent respiratory acidosis
         (6) Hypoxemia
         (7) Transient ruminal amotility (in cattle)
         (8) Diuresis
         (9) Salivation (in cattle)
      b. The side effects in cattle are dose-dependent and partially reversed by administration of tolazoline (0.3 mg/kg slowly IV or IM)
   2. Horses: xylazine (0.2 to 0.4 mg/kg-check dose-higher in Table 4-5) or detomidine [30 to 60 μg/kg] expanded to a 6 mL to 10 mL volume with sterile saline solution) given in the epidural space at the first coccygeal intervertebral space, produces anesthesia in the anal and perineal region for surgery and obstetric procedures, with minimal ataxia (see Table 4-5)
      a. Side effects (see above)
   3. Pigs: xylazine (2 mg/kg expanded to a 0.5 to 1.0 mL/ 10 kg volume with sterile saline solution) given in the epidural space at the lumbosacral, the sacrococcygeal, or first intercoccygeal space produces bilateral surgical anesthesia of the trunk caudal to the umbilicus and analgesia and paralysis of rear limbs, with minimal cardiovascular depression (see Table 4-4)
      a. Smaller doses of epidural xylazine (<1 mg/kg) do not produce surgical anesthesia

b. Larger doses of epidural xylazine (>3 mg/kg) induce weakness of rear limbs for 36 hours or longer

4. Adult goats: xylazine (0.15 mg/kg expanded to a 5 mL volume with sterile saline solution) given in the epidural space at the lumbosacral space produces analgesia of the flank and perineum, which extends to the head and forelimb. Frequently produces lateral recumbency.
5. Dogs and cats: medetomidine or dexmedetomidine (5 to 10 μg/kg; 1 mL of sterile saline/2.5 kg) can be added to a local anesthetic and/or opioid and administered in the epidural space to produce regional analgesia

C. Onset and duration of epidural analgesia
1. Signs of analgesia develop within 10 to 30 minutes (compared with 5 to 10 minutes after epidural lidocaine)
2. A mixture of xylazine and lidocaine can be used to shorten the onset of analgesia to about 5 minutes and prolong analgesia up to about 5 hours (see Table 4-5)
   a. Duration of analgesia is longer for the xylazine-lidocaine combination than for either drug used alone
   b. Duration of analgesia after epidural drug administration is highly variable (see Table 4-4)
      (1) Duration is 110 minutes after lidocaine
      (2) Duration is 220 minutes after xylazine
      (3) Duration is 330 minutes after xylazine-lidocaine combination
   c. Surgical and obstetric procedures can commence after injection without the need for additional anesthetic

D. α-Antagonists
1. Atipamezole (0.1 to 0.2 mg/kg), a potent α_2-adrenoceptor antagonist, when injected IV does not abolish the analgesic or immobilizing effects of epidurally administered xylazine in pigs
2. Tolazoline (0.3 mg/kg), an α_1- and α_2-adrenoceptor antagonist, does not reverse xylazine-induced epidural analgesia in cattle when injected IV

E. Epidural detomidine
1. Horses: detomidine (0.06 mg/kg expanded to a 10 mL volume with sterile saline solution) given in the epidural space at the first coccygeal intervertebral space produces variable analgesia. Analgesia may extend from the coccyx to the third sacral (S3) and coccyx to the fourteenth thoracic (T14) spinal cord segment (see Table 4-5).

a. Detomidine-induced caudal epidural analgesia in horses is associated with side effects
   (1) Marked sedation, head drop
   (2) Bradycardia with second-degree atrioventricular heart block
   (3) Hypotension
   (4) Hypercarbia (respiratory depression with subsequent respiratory acidosis)
   (5) Diuresis
2. These side effects are dose-dependent and can be partially antagonized by atipamezole (0.2 mg/kg IV)

NOTE: Alpha-2 agonists are often administered epidurally in conjunction with low dosages of local anesthetics (lidocaine [0.3-0.5 mg/kg; bupivacaine 0.25-0.3 mg/kg] or opioids (morphine 0.1 mg/kg)

F. Epidural medetomidine; dexmedetomidine
1. Cattle**:** medetomidine (15 μg/kg expanded to a 5 mL volume with sterile saline solution) given in the epidural space at the second coccygeal space produces variable analgesia (see Table 4-4)
   a. Onset of analgesia is 5 to 10 minutes and is maintained up to 7 hours
   b. Medetomidine-induced caudal epidural analgesia in cattle is associated with side effects
      (1) Mild to moderate sedation
      (2) Moderate ataxia
      (3) Salivation
      (4) Diuresis
2. Goats: medetomidine (20 μg/kg expanded to a 5 mL volume with sterile saline solution) given in the epidural space at the lumbosacral space produces adequate analgesia of the flank and perineum
   a. Analgesia extends to the thorax, forelimbs, neck, and head, with variable cardiopulmonary depression
   b. The duration of analgesia is 2 hours
   c. Analgesia and cardiopulmonary depression are reversed by atipamezole (80 μg/kg IV)
3. Dogs: medetomidine (or dexmedetomidine: 15 μg/kg) given in the epidural space at the lumbosacral space produces variable analgesia

a. Medetomidine-induced caudal epidural analgesia in dogs may be associated with side effects such as bradycardia with second-degree atrioventricular heart block
b. The duration of analgesia is 7 hours

4. Cats: medetomidine (or dexmedetomidine: 10 μg/kg in 1 mL saline solution) given in the epidural space at the lumbosacral space produces variable analgesia
   a. The pain threshold for the hindlimbs increases during period of 20 to 245 minutes after injection
   b. The pain threshold for the forelimbs also increases, during period of 15 to 120 minutes after injection
   c. Produces mild sedation for a short period (3 to 10 minutes)

NOTE: Restraint: movements of head, shoulder, and forelimbs are not suppressed by epidural analgesia/anesthesia and should be controlled by physical or chemical restraint

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G. Subarachnoid xylazine
   1. Goats: xylazine (50 μg/kg) given into the lumbosacral subarachnoid space produces moderate analgesia of hind quarter, perineum, and flank; mild ataxia; and sedation
      a. Minimal changes in hemodynamic, hematologic, physiological, and biochemical parameters
      b. The onset of analgesia is within 10 minutes and the duration is 2 hours

H. Subarachnoid detomidine
   1. Horses: detomidine (30 μg/kg expanded to a 3 mL volume with cerebrospinal fluid) given into the subarachnoid space at midsacral vertebrae (catheter technique) produces analgesia and side effects similar to those produced by epidural administration of detomidine (60 μg/kg)
      a. Most of the side effects, except bradycardia and bradypnea, are reversed by atipamezole (0.1 mg/kg IV)
      b. The duration of analgesia is shorter than that after epidural administration; 2 hours and 2.5 hours, respectively

III. Subarachnoid medetomidine

A. Goats: medetomidine (10 μg/kg) given into the lumbosacral subarachnoid space produces effects similar to xylazine (50 μg/kg)

5 Local Anesthesia in Ruminants and Pigs

"The pain of the mind is worse than the pain of the body."
PUBLILIUS SYRUS

OVERVIEW

The most commonly used local anesthetic techniques in ruminants are surface (topical) anesthesia, infiltration anesthesia, nerve block (conduction) anesthesia, epidural anesthesia, and intravenous regional anesthesia. The standing position is optimal for surgery in large ruminants because it reduces the problems associated with bloating, salivation, recumbency-related regurgitation, and nerve or muscle damage.

The most commonly used local anesthetic techniques in appropriately tranquilized pigs are infiltration anesthesia, lumbosacral epidural anesthesia, and intratesticular injection.

Ruminants: Local Anesthesia for Standing Laparotomy

I. Four techniques for producing local anesthesia of the paralumbar fossa in ruminants:
- A. Infiltration anesthesia
- B. Proximal paravertebral anesthesia
- C. Distal paravertebral anesthesia
- D. Segmental dorsolumbar epidural anesthesia

II. Abdominal surgeries in which these anesthetic techniques may be used:
- A. Rumenotomy
- B. Cecotomy
- C. Correction of gastrointestinal displacement
- D. Intestinal obstruction
- E. Volvulus
- F. Cesarean section
- G. Ovariectomy
- H. Liver or kidney biopsy

III. Infiltration anesthesia
- A. Line block
  1. Area blocked: skin and muscle layers of the flank and parietal peritoneum along the line of incision

2. Needle: 18-gauge, 7.6- to 10.2-cm
3. Anesthetic: 10 to 100 mL of 2% lidocaine
4. Method: make multiple subcutaneous injections of 0.5 to 1.0 mL of anesthetic, 1 to 2 cm apart with a 20-gauge, 2.54-cm needle; then infiltrate the muscle layers and parietal peritoneum through the desensitized skin.
5. Advantages
   a. Easiest technique
   b. Use of routinely sized needles (2.5-cm, 20-gauge or smaller for skin block; 7.6- to 10.2-cm, 18-gauge for infiltrating the muscle layers and peritoneum).
6. Disadvantages
   a. Large volume of anesthetic
   b. Lack of muscle relaxation
   c. Incomplete block of deeper layers of the abdominal wall
   d. Formation of hematomas along the incision line
   e. Increased cost because of larger amounts of anesthetic used and time required
7. Complications
   a. Toxicity can occur if a significant amount of anesthetic of 2% lidocaine (e.g., 250 mL [5 g] is inadvertently administered intraperitoneally to a 450 kg cow or 10 mL [200 mg] is administered intraperitoneally to an adult goat)
   b. Interference with healing

B. Inverted L block (Fig. 5-1)
1. Area blocked: flank caudal and ventral to site of injection
2. Site: a line along the caudal border of the last rib and along a line ventral to the lumbar transverse processes from the last rib to the fourth lumbar vertebra (inverted L)
3. Needle: 18-gauge, 7.6-cm
4. Anesthetic: up to 100 mL of 2% lidocaine in adult cattle, evenly distributed
5. Method: inject drug into the tissues bordering the dorsocaudal aspect of the last rib and ventrolateral aspect of the lumbar transverse processes, creating a wall of anesthetic enclosing the incision site
6. Advantages
   a. Similar to line block
   b. Absence of anesthetic agent from the incision line minimizes edema, hematoma, and possible interference with healing

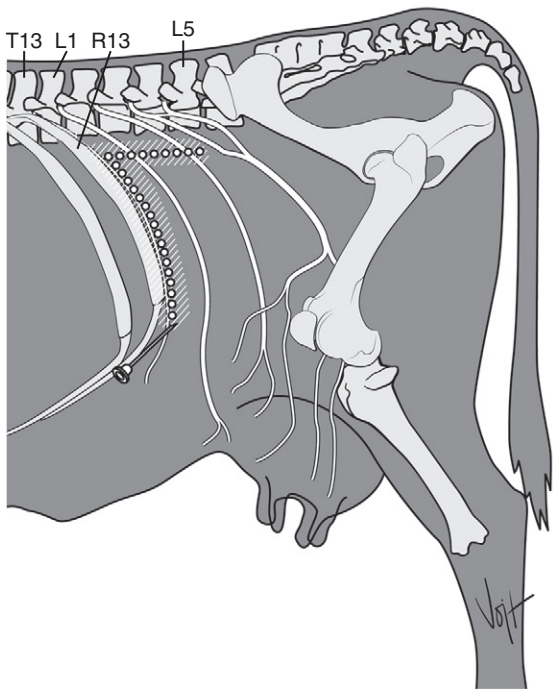


FIG. 5-1. Regional anesthesia of a cow's left flank using inverted L infiltration pattern.

7. Disadvantages
   a. Large volume of anesthetic required
   b. Length of time required to infiltrate such a long line
   c. Incomplete block of the deep layers of the abdominal wall (particularly the peritoneum)
8. Complications: similar to line block

IV. Specific nerve anesthesia

A. Proximal paravertebral anesthesia (Farquharson, Hall, or Cambridge technique)
   1. Area blocked: flank of side on which technique is performed
   2. Nerves blocked: dorsal and ventral branches of T13, L1, and L2 and occasionally L3 and L4 (desensitization of L3 and L4 produce analgesia of the caudal-most part of the paralumbar fossa for cesarean section or ipsilateral foreteat and mammary gland; if L3 and L4 are blocked, the animal may become unable to stand)

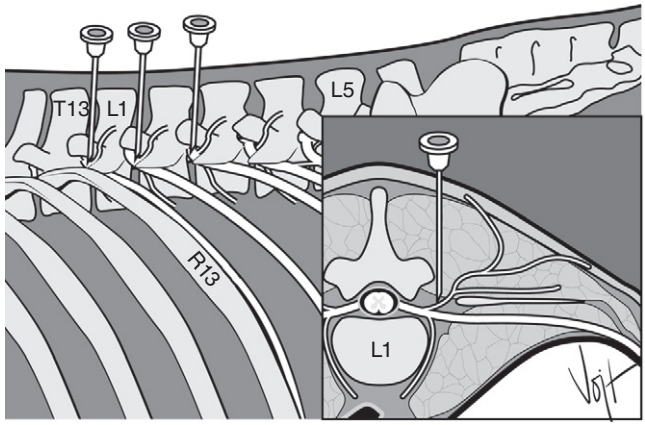


FIG. 5-2. Needle placement for proximal paravertebral nerve block in cattle. Left lateral aspect and cranial view of a transection of the first thoracolumbar vertebra at the location of the intervertebral foramen. R13 is the last rib; T13, L1, and L5 are the spinous processes of the last thoracic and the first and fifth lumbar vertebrae, respectively.

3. Site: 2.5 to 5 cm from midline (Fig. 5-2); T13 immediately in front of transverse process of L1; L1 immediately in front of transverse process of L2; L2 immediately in front of transverse process of L3
4. Needle: 14-gauge, 1.3-cm needle, creating passage for a 16- or 18-gauge, 3.81- to 15.2-cm needle
5. Anesthetic: 20 mL of 2% lidocaine at each site
6. Method: the skin overlying the spinal column on the side to be desensitized is clipped, surgically scrubbed, and disinfected; palpate the lumbar transverse processes, starting from L5 and moving forward; L1 may be difficult to feel; measure 5 cm from midline; palpate the lumbar dorsal processes; injection site is at a 90-degree angle to the spaces between the dorsal processes; pass the needle vertically down until it hits the cranial edge of the transverse process and proceed down through the intertransverse ligament; inject 10 to 15 mL of 2% lidocaine below the ligament to block the ventral branch of the nerve (there should be minimal resistance to injection); withdraw the needle 1 to 2.5 cm sufficiently to inject 5 mL of 2% lidocaine above ligament, level with dorsal surface of transverse process to block the dorsal

branch (resistance to injection); if the first lumbar transverse process cannot be palpated, anesthetize the other nerves first and then measure the distance between injection sites to find the site for blocking nerve T13

7. In sheep and goats, T13, L1, and L2 are desensitized in a fashion similar to the cattle method, but 2.5 to 3 cm off the midline and with less anesthetic (2 to 3 mL per site)
8. Advantages over local block
   a. Anesthesia of skin, musculature, and peritoneum; wide and uniform area of analgesia and muscle relaxation
   b. No additional restraint required
   c. Large quantities of local anesthetic not required
   d. Shorter postsurgical convalescent period; incision site avoided
9. Disadvantages
   a. Procedure difficult in fat cattle and some beef cattle
   b. Arching of the spine caused by paralysis of back muscles
   c. No anesthesia of abdominal viscera
   d. Bowing out toward the area of incision (after unilateral blockade), making the closure of the incision more difficult
10. Complications
    a. Possible penetration of the aorta
    b. Possible penetration of the thoracic longitudinal vein (posterior) or vena cava
    c. Loss of motor control of the pelvic limb caused by caudal migration of drug (femoral nerve block)

B. Distal paravertebral anesthesia (Magda, Cakala, or Cornell technique)
   1. Area blocked: flank of side on which technique is performed
   2. Nerves blocked: dorsal and ventral rami of T13, L1, and L2
   3. Site: distal ends of lumbar transverse processes of L1, L2, and L4 (Fig. 5-3)
   4. Needle: 18-gauge, 7.6-cm
   5. Anesthetic: 10 to 20 mL of 2% lidocaine at each site
   6. Method: the skin overlying the spinal column on the side to be desensitized is clipped, surgically scrubbed, and disinfected; insert the needle ventral to the tips of the respective transverse process; inject anesthetic (up to 20 mL) in a fan-shaped infiltration pattern; withdraw the

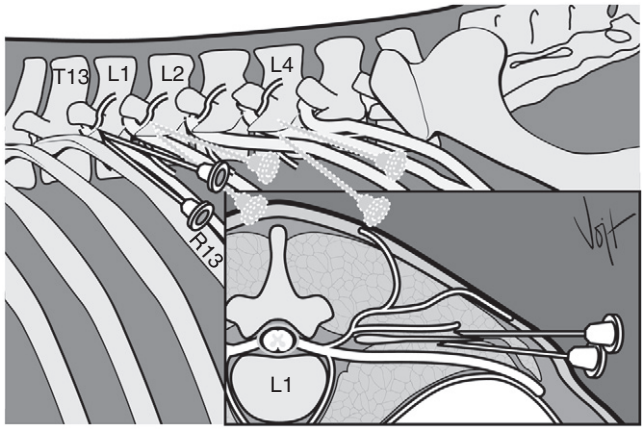


FIG. 5-3. Needle placement for distal paravertebral nerve blockade in cattle. Left lateral aspect and cranial view of a transection of the first lumbar vertebra at the location of the intervertebral foramen. R13 is the last rib; T13, L1, L2, and L4 are the spinous processes of the last thoracic and first, second, and fourth lumbar vertebrae.

needle a short distance, reinsert it dorsal and caudal to the transverse process, and inject approximately 5 mL of the anesthetic.

7. Advantages of distal paravertebral nerve block over proximal paravertebral block
   a. Use of routinely sized needles
   b. Minimizes risk of penetrating a major blood vessel
   c. Lack of scoliosis
   d. Minimal ataxia or weakness in the pelvic limb
8. Disadvantages
   a. Larger volume of anesthetic
   b. Variations in efficacy, particularly if the nerves follow a variable anatomic pathway
9. Complications: none

C. Segmental dorsolumbar epidural block (Arthur block)
1. Area blocked: the skin area caudal to the T13 or L1 spinous process and flank on both sides
2. Nerves blocked: T13 and anterior lumbar nerves, depending on the total dose administered
3. Site: epidural space between L1 and L2 vertebrae (Fig. 5-4)
4. Needle: spinal, preferably 18-gauge, 12.7-cm
5. Anesthetic: 8 mL of 2% lidocaine in a 500-kg cow, no more than 1 mL/50 kg of 2% lidocaine in sheep and goats

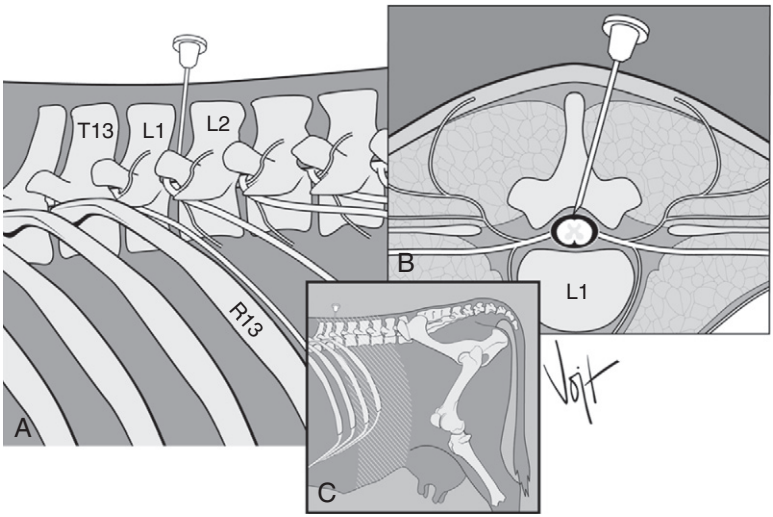


FIG. 5-4. Needle placement for segmental dorsolumbar epidural block. **A,** Left lateral aspect. **B,** Cranial view of a transection of the first lumbar vertebra at the location of the intervertebral foramen. **C,** (inset) Desensitized area of skin after segmental epidural anesthesia (lightly shaded area). R13 is the last rib; T13, L1, and L2 are the spinous processes of the last thoracic and first and second lumbar vertebrae.

6. Method: the skin overlying the spinal column is clipped, surgically scrubbed, and disinfected; to reach the epidural space, insert the spinal needle 8 to 12 cm ventral and cranial at an angle of 10 to 15 degrees from vertical; piercing of the interarcuate ligament is felt as slight resistance during the insertion process; no blood or cerebrospinal fluid (CSF) can be aspirated, and also no resistance to the injection of anesthetic results after correct needle placement; if bleeding occurs, the stylet is placed into the needle and the needle is withdrawn after 2 to 3 minutes
7. Advantages over proximal or distal paravertebral anesthesia
   a. Only one injection
   b. Small quantity of anesthetic
   c. Uniform anesthesia and relaxation of the skin, musculature, and peritoneum (begins 10 to 20 minutes after administration and continues for 45 to 120 minutes)

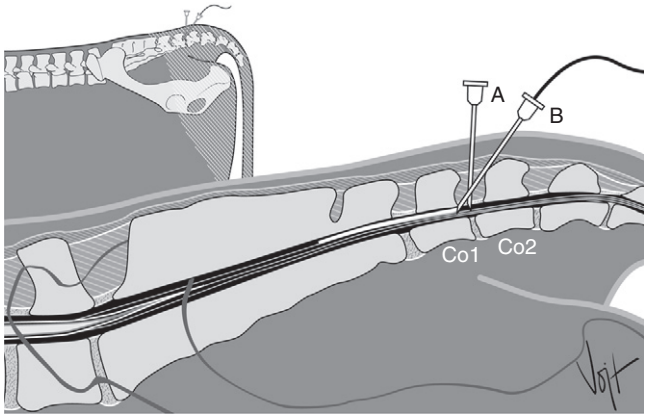


FIG. 5-5. Needle placement for (**A**) caudal epidural anesthesia and (**B**) continuous caudal epidural anesthesia in cattle. Co1 is the first coccygeal vertebra, and Co2 is the second coccygeal vertebra. Desensitized area of skin is patterned in figure above.

8. Disadvantages
   a. Difficult technique to perform
   b. Potential for trauma to the spinal cord or venous sinuses
9. Complications
   a. Loss of motor control of the pelvic limbs caused by overdose or subarachnoid injection
   b. Physiologic disturbance caused by overdose or subarachnoid injection
   c. Potential for trauma to the spinal cord or venous sinuses

Anesthesia for Obstetric Procedures and Relief of Rectal Tenesmus

I. Caudal epidural anesthesia and desensitization of the internal pudendal nerve are commonly used in ruminants for obstetric manipulations, caudal surgical procedures, and as an adjunct treatment for control of rectal tenesmus; these techniques are not effective in pigs.

II. Cattle

A. Low posterior or caudal epidural anesthesia
   1. Area blocked: anus, perineum, vulva, and vagina
   2. Nerves blocked: coccygeal and posterior sacral nerves

3. Site: first intercoccygeal space (Co1 to Co2: Fig. 5-5, *A*; more commonly and easily) or sacrococcygeal space (S5 to Co1)
4. Needle: 18-gauge, 3.8- to 5.1-cm (average dairy cow)
5. Anesthetic: 5 to 6 mL of 2% lidocaine or other drugs (Table 4-2)
6. Method: the skin overlying the spinal column is clipped, surgically scrubbed, and disinfected; locate the sacrococcygeal joint by moving the tail up and down; this joint moves very little and is located just anterior to the anal folds; the first intercoccygeal joint is easily located by its movement; it is much wider and is posterior to the anal folds; insert the needle exactly at the midline of the first intercoccygeal space at a right angle (approximately 10 degrees to vertical) to the skin surface; push the needle ventrally through the interarcuate ligament to the floor of the neural canal, which is at approximately 2 to 4 cm; withdraw the needle slightly (about 0.5 cm) into epidural space and test by injecting 1 mL of air; no resistance should be felt
7. Advantages
   a. Minimal effect on cardiovascular and respiratory systems
   b. Little effect on organ systems
   c. Little problem with toxicity
   d. Good muscle relaxation
   e. Good postoperative analgesia
   f. Rapid recovery
   g. Relatively simple
   h. Inexpensive
8. Disadvantages
   a. Technically difficult if Co1 to Co2 interspace is not identified
   b. Technically difficult if the sacrococcygeal interspace is ossified in older cows
9. Complications
   a. Rare
   b. Infection resulting in draining tracts or permanently paralyzed tail
   c. Possible ataxia and collapse caused by overdose
   d. Hemorrhage caused by puncture of a venous sinus

B. Continuous caudal epidural anesthesia
   1. Indications: prolapse of the vagina and/or rectum that provokes severe continuous straining
   2. Nerves blocked: coccygeal and posterior sacral nerves
   3. Site: first intercoccygeal space; Co1 to Co2 (or sacrococcygeal space; S5 to Co1) (Fig. 5-5, *B*)
   4. Needle: 16- or 17-gauge, 7.6-cm, thin-walled, Huber Point directional needle or Hustead needle
   5. Catheter: 30-cm, medical-grade vinyl catheter (0.036 cm outside diameter) or a commercially available epidural catheter with graduated markings
   6. Anesthetic: 3 to 5 mL of 2% lidocaine every 4 to 6 hours
   7. Method: the skin overlying the spinal column is clipped, surgically scrubbed, and disinfected; identify the first intercoccygeal joint as previously described; desensitize the skin and needle tract; with stylet in place and bevel directed cranially, advance the spinal needle 5 to 8 cm approximately 45 degrees to vertical, until an abrupt reduction in resistance to needle passage is noted; remove the stylet from the needle and inject 3 mL (test dose) of 2% lidocaine with minimal resistance; the test dose ensures proper placement of the needle in the vertebral canal; place the catheter aseptically, introduce into the canal through the needle, and advance it cranially approximately 3 to 4 cm beyond the tip of the needle (see Fig. 5-5, *B*); withdraw the needle, leaving the catheter in position; inject local anesthetic solution into the catheter at 4- to 6-hour intervals or as needed; place a catheter adapter on the free end of the catheter; secure the catheter at the entrance into the skin with adhesive tape sutured to the skin; place a protective sterile gauze over the free end of the catheter to allow the catheter to be used for many hours of infusion in the field
   8. Advantages
      a. Similar to caudal epidural anesthesia
      b. Repeated administration of small fractional doses of local anesthesia
      c. No fibrosis of the extradural space from repeated standard epidural blocks
   9. Disadvantages
      a. Similar to caudal epidural anesthesia

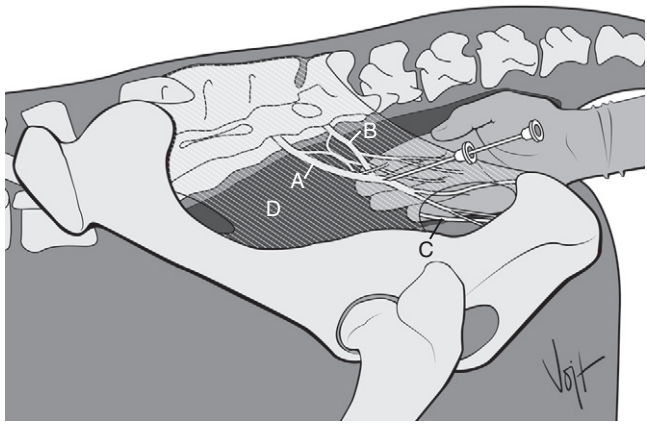


FIG. 5-6. Right hand inserted in the rectum of a cow and needle placement at the internal pudendal nerve on the medial side of the left pelvis. **A,** Internal pudendal nerve. **B,** Pelvic splanchnic nerves. **C,** Pudendal artery. **D,** Sacrosciatic ligament.

   b. Greater cost of equipment
   c. Acute tolerance to repeated injections
10. Complications
   a. Similar to caudal epidural anesthesia
   b. Kinking and curling of the catheter and occlusion of the tip with fibrin

C. Internal pudendal nerve block
1. Indications
   a. Analgesia and relaxation of the penis for examination
   b. Relief of tenesmus associated with vaginal and uterine prolapse
2. Nerves blocked: internal pudendal (fibers of the ventral branches of S3 and S4), caudal rectal (fibers of the ventral branches of S4 and S5), and pelvic splanchnic nerves
3. Site: identified by rectal palpation (Fig. 5-6)
4. Needle: spinal, preferably 18-gauge, 10.2-cm
5. Anesthetic: up to 35 mL of 2% lidocaine per side
6. Method: use rectal palpation to locate the lesser sciatic foramen, a soft, circumscribed depression in the sacrosciatic ligament; find the nerve a finger's width dorsal to the pudendal artery present in the fossa; pass the needle through the disinfected skin in the ischiorectal fossa; deposit up to 25 mL of 2% lidocaine around the nerve;

withdraw and direct the needle 2 to 3 cm caudodorsally and inject another 10 mL of the anesthetic in the area of the pelvic splanchnic nerve; repeat the procedure on the opposite side of the pelvis

7. Advantages
   a. No loss of tail tone
   b. No sciatic nerve involvement
   c. Ballooning of the vagina may aid in retention of the vagina after it is repositioned in a cow with prolapse
8. Disadvantages
   a. Technical difficulty and necessity of identifying the injection sites by rectal palpation
   b. Lack of cervical anesthesia
   c. Anesthesia duration of 3 to 6 hours
   d. Larger volume of anesthetic
9. Complications: injury to the bull's penis, which must be protected from injury by replacing it into the prepuce

III. Sheep and goats: low posterior or caudal, epidural anesthesia

A. Similar to that used in cattle

B. Excellent for tail docking in lambs and intravaginal obstetric procedures

C. Alcohol-epidural injection for continuous caudal epidural anesthesia
   1. Can be used for long-term demyelinization
   2. First, inject 0.5 to 1 mL/50 kg of 2% lidocaine hydrochloride epidurally as a test; after full sensation has returned, inject a mixture of equal volumes of 70% to 95% ethyl or isopropyl alcohol and 2% lidocaine solution; analgesia of the pelvic and perineal area and paralysis of the tail lasts from a few days to several months
   3. Inflammation, necrosis, and purulence can occur because of fly strike

D. Internal pudendal nerve block
   1. Needle: spinal, 18-gauge, 3.8-cm
   2. Anesthetic: 3 to 5 mL of 2% lidocaine per site
   3. Method: Place a gloved finger into the rectum to locate the slit-like sciatic foramen; insert a needle through the corresponding skin site while advancing its point to the foremen and inject 3 to 5 mL of the anesthetic; withdraw the needle and massage the injection site; repeat the procedure on the opposite side of the pelvis

Anterior Epidural Anesthesia

I. Anterior epidural anesthesia can be used for all procedures caudal to the diaphragm; the lumbosacral space is commonly used in calves, sheep, and goats because the injection sites are usually palpable; this space is the only practical injection site for producing anterior anesthesia in pigs. The sacrococcygeal or first intercoccygeal space is the injection site of choice in adult cattle for producing anterior anesthesia, because the technique is relatively simple and avoids trauma to the spinal cord and meninges; proper techniques should provide anesthesia of the following areas:
   A. Perineal region
   B. Inguinal region
   C. Flank
   D. Abdominal wall caudal to the umbilicus

II. Increasing the dose (volume × concentration) of the anesthetic increases the area of blockade
   A. Increasing the volume improves segmental spread
   B. Increasing the concentration produces a more rapid onset, greater effects, and longer duration of analgesia and motor blockade

III. Rapid epidural injections must be avoided to prevent complications
   A. Discomfort to the animal
   B. Increased rate of vascular absorption, which can result in less drug for neural uptake; reduced neural uptake can result in the following:
      1. Reduced duration of action
      2. Higher incidence of incomplete anesthesia
      3. Only a slight increase in segmental spread

IV. The technique is contraindicated in animals with certain known conditions:
   A. Severe cardiovascular disease
   B. Bleeding disorders
   C. Shock or toxemic syndromes because of sympathetic block and resulting depression of blood pressure

V. The following complications may result from overdose or subarachnoid injection:
   A. Transient loss of consciousness
   B. Flexor spasm
   C. Rapid muscular contractions
   D. Convulsions

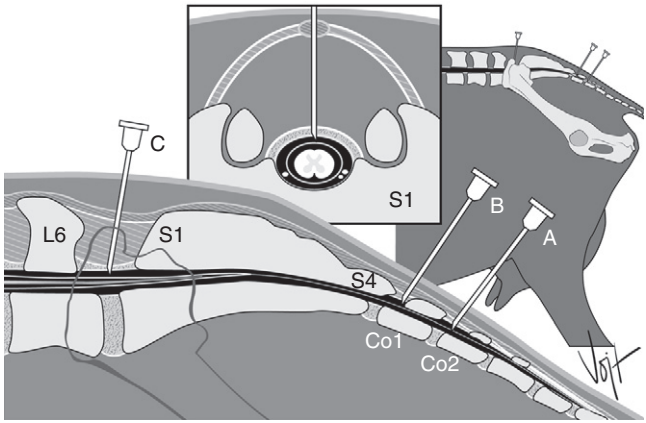


FIG. 5-7. Needle placement for caudal epidural anesthesia (**A** and **B**) and anterior epidural anesthesia (**C**) in the goat. Lateral aspect and cranial view of a transection to the first sacral vertebra. A needle is placed into ***A*,** the first intercoccygeal vertebral space; ***B*,** the sacrococcygeal space; and ***C*,** the lumbosacral space.

E. Respiratory paralysis
F. Hypotension
G. Hypothermia
H. Possibly headache after dural puncture (changes in CSF pressure)

VI. Small ruminants (sheep and goats)
A. Landmarks and techniques for injection at the lumbosacral space are similar to those used in dogs (Fig. 5-7); the site for needle placement is usually palpable as a depression on the midline just caudal to a line joining the anterior border of the ilium on each side.
B. Dose: 0.2 mL/kg of body weight of 2% lidocaine
C. Effect
1. Onset of posterior paralysis occurs in 2 to 15 minutes
2. Anesthesia generally reaches three fourths of the distance from pubis to umbilicus
3. Duration of action is 1 to 2 hours
4. Similar extent and duration of anesthesia can be achieved if only half the dose (0.1 mL/kg) is injected subarachnoidally (the space from which spinal fluid is aspirated into the syringe) at a rate of 1 mL every 2 to 3 seconds; true CSF anesthesia results with the onset of posterior paralysis within 1 to 3 minutes and lasts 60 to 90 minutes; anesthesia may extend to the last rib

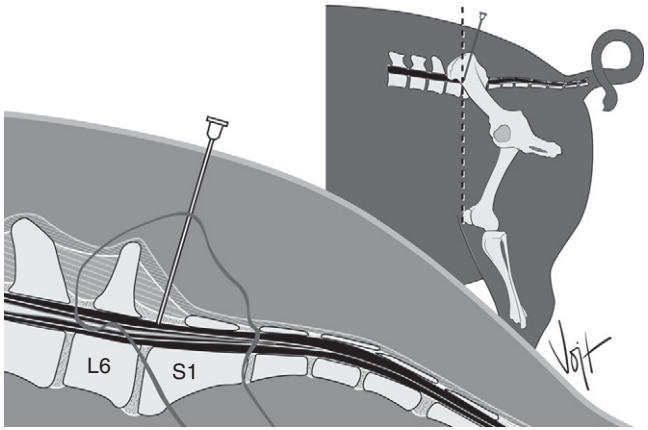


FIG. 5-8. Needle placement for epidural anesthesia in the pig. L6 is the sixth lumbar vertebra, and S1 is the first sacral vertebra.

5. Gravity, not diffusion of drug in the CSF, determines the spread of anesthesia
6. Morphine (0.1 mg/kg) diluted with saline solution to a volume of 5 mL can be injected epidurally after orthopedic procedures to produce 9 or more hours of analgesia and sedation with minimal cardiopulmonary complications

VII. Pigs

A. Used for
   1. Cesarean section
   2. Repair of rectal, uterine, or vaginal prolapses
   3. Repair of umbilical, inguinal, or scrotal hernias
   4. Surgery of scirrhous cord
   5. Surgery of the prepuce, penis, or rear limbs

B. Landmarks and techniques for injection at the lumbosacral space are similar to those used in dogs and small ruminants (Fig. 5-8)

C. Dose when using 2% lidocaine: calculated by either weight or length of the pig
   1. By weight
      a. 1 mL/5 kg
      b. 1 mL/7.5 kg for pigs up to 50 kg and an additional 1 mL/10 kg
   2. By length
      a. 1 mL for the first 40 cm of back length from the base of the tail and an additional 1.5 mL/10 cm

Lumbosacral Epidural Anesthesia in Pigs

Standing Castration	Cesarean Section
4 mL/100 kg	10 mL/100 kg
6 mL/200 kg	15 mL/200 kg
8 mL/300 kg	20 mL/300 kg

D. Effect
   1. Onset of anesthetic action generally occurs within 5 minutes
   2. Maximum effect is within 15 to 20 minutes
   3. Duration of action is 120 minutes
   4. Most pigs develop posterior paresis

Local Anesthesia For Dehorning

I. Cattle
   A. Area blocked: horn and base of the horn
   B. Nerves blocked: cornual branch of zygomaticotemporal (lacrimal) nerve, a portion of the ophthalmic division of the trigeminal nerve
   C. Site: temporal ridge, 2 to 3 cm from the base of horn (Fig. 5-9); needle penetration is from 1 cm in small cattle to 2.5 cm in large bulls
   D. Needle: 18-gauge, 2.54-cm
   E. Anesthetic: 5 to 10 mL of 2% lidocaine
   F. Method: palpate the lateral temporal ridge of the frontal bone; the nerve is relatively superficial, 7 to 10 mm deep on the upper third of the ridge, lying between the thin frontalis muscle and the temporal muscle, and can usually be palpated between these muscles; aspiration ensures that the needle point is not inadvertently intravascular; inject 2 to 3 cm in front of the base of the horn
   G. Advantages
      1. Minimal systemic effects on the cardiopulmonary system
      2. Relatively simple procedure
   H. Disadvantages
      1. Cornual anesthesia does not result if the anesthetic is injected too deeply in the aponeurosis of the temporal muscle
      2. A second injection posterior to the horn may be required in adult cattle with well-developed horns

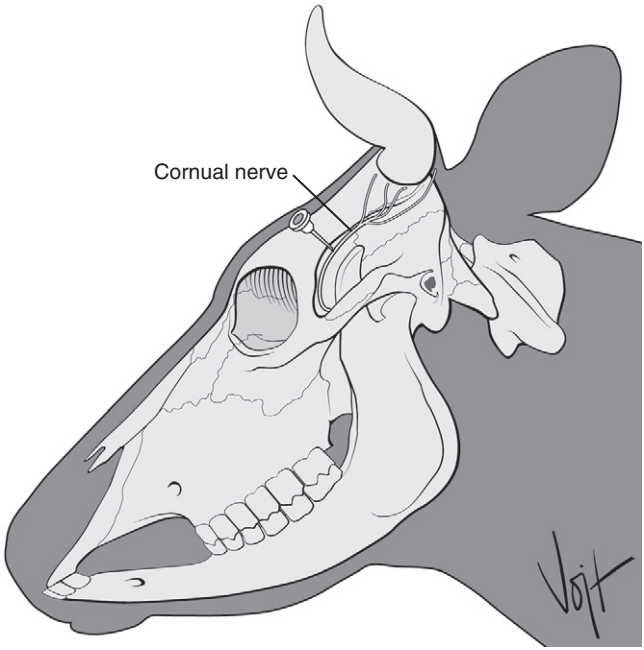


FIG. 5-9. Needle placement for desensitizing the cornual branch of the zygomaticotemporal nerve in the cow.

3. Anesthesia of a fractured horn involving the frontal bone or sinuses may require a Peterson eye block

I. Complications: none

II. Goats

A. Area blocked: horn and base of the horn

B. Nerves blocked: cornual branch of the zygomaticotemporal (lacrimal) nerve and cornual branch of the infratrochlear nerve

C. Site: halfway between lateral canthus of the eye and lateral base of the horn (lacrimal nerve) (Fig. 5-10, *A*) and halfway between medial canthus of the eye and medial base of the horn (cornual branch of infratrochlear nerve) (Fig. 5-10, *B*)

D. Needle: 22-gauge, 2.54-cm

E. Anesthetic: 2 to 3 mL of 2% lidocaine at each site in the adult goat; no more than 0.5 mL of 2% lidocaine per site (or 1 mL of 1% lidocaine) for ring block at the horn base in young kids 7 to 14 days of age

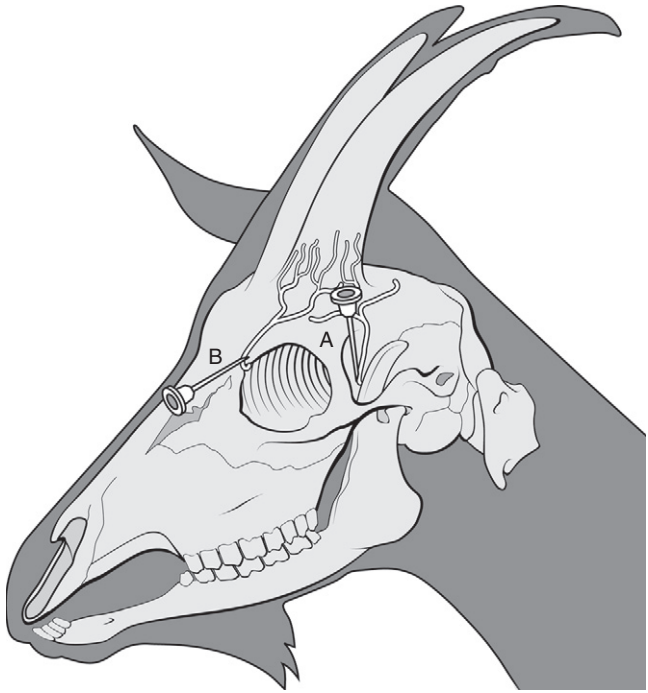


FIG. 5-10. Needle placement for desensitizing (***A***) the cornual branch of the zygomaticotemporal (lacrimal) nerve and (***B***) the cornual branch of the infratrochlear nerve in the goat.

F. Method: to reach the cornual branch of the zygomaticotemporal nerve, insert the needle as close as possible to the caudal ridge of the supraorbital process and 1 to 1.5 cm deep (see Fig. 5-10, *A*); to reach the cornual branch of the infratrochlear nerve, insert the needle dorsal and parallel to the dorsomedial margin of the orbit; inject the anesthetic in a line, because this nerve is frequently branched (Fig. 5-10, *B*)

G. Advantages
   1. Alleviation of pain during dehorning
   2. Alleviation of pain during disbudding

H. Disadvantages
   1. Sedation of the animal is required if the frontal sinus will be entered during horn removal
   2. A total dose of 10 mg/kg (0.5 mL of 2% solution per kilogram or 1 mL of a 1% solution per kilogram) must not be exceeded to minimize adverse reactions

I. Complications: toxicity caused by overdose of lidocaine and any of the following clinical signs:
   1. Excitation
   2. Lateral recumbency
   3. Muscular twitching
   4. Generalized tonic-clonic convulsions
   5. Opisthotonus
   6. Coma
   7. Respiratory depression
   8. Cardiac arrest

Local Anesthesia for the Eye

I. Topical and regional anesthetic techniques are used for surgery of the eye and its associated structures; paralysis of the eyelids (without analgesia) is accomplished by selectively desensitizing the auriculopalpebral branch of the facial nerve (producing akinesia); anesthesia of the eye and orbit and immobilization of the globe are commonly achieved by the Peterson technique (Fig. 5-11, *A*)
   A. Area blocked: eye and orbit, orbicularis oculi muscle, except the eyelids
   B. Nerves blocked: oculomotor, trochlear, and abducens nerves and the three branches of the trigeminal nerve (ophthalmic, maxillary, and mandibular)
   C. Sites: the points at which these nerves emerge from the foramen orbitorotundum
   D. Needle: 14-gauge, 2.5-cm to serve as a cannula; 18-gauge, 10.2- to 12.7-cm
   E. Anesthetic: 7 to 15 mL of 2% lidocaine at the foramen orbitorotundum; 5 to 10 mL of 2% lidocaine for desensitizing the auriculopalpebral nerve
   F. Method
      1. Fully extend cow's head in a standing position with frontal and nasal bones parallel to the ground
      2. Surgically prepare area posterior and ventral to the eye
      3. Inject several milliliters of anesthetic with a small-gauge needle into the skin and subcutaneously into the notch formed by the zygomatic and temporal process of the malar bone (where the supraorbital process of the frontal bone meets the zygomatic arch) (Fig. 5-11, *B*)
      4. Place a 14-gauge, 1.3- to 2.54-cm needle (to serve as a cannula) through the skin as far anterior and ventral as possible in the notch

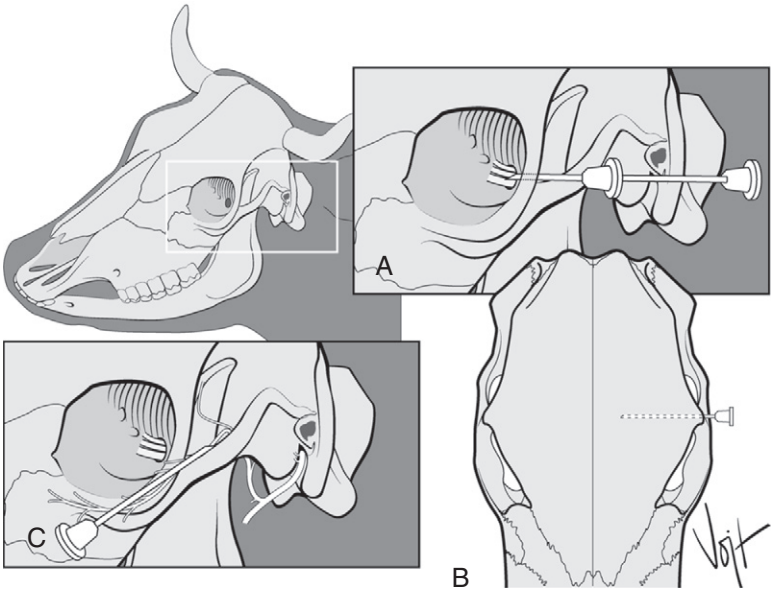


FIG. 5-11. Needle placement for Peterson eye block, with needle tip at the foramen orbitorotundum. **A,** Craniolateral aspect. **B,** Dorsal aspect. **C,** Needle placement for akinesia of the eyelids in the cow.

5. Direct a straight, 18-gauge, 12.7-cm needle with no syringe attached (to feel the bony landmarks) through the cannula in a horizontal and slightly posterior direction, until it strikes the coronoid process of the mandible
6. Reposition the point of the needle anteriorly until it passes medially around this bone
7. Advance needle slightly posteriorly and somewhat ventrally until it strikes a solid bony plate, which is at a depth of 7.6 to 10.2 cm
8. Inject 15 mL of 2% lidocaine anterior to the foramen orbitorotundum
9. Block the auriculopalpebral branch of the facial nerve (Fig. 5-11, *C*)
   a. Fill a 10-mL syringe with local anesthetic, attach it to the needle, and partially withdraw the cannula
   b. Withdraw the needle until it almost leaves the skin and direct it posteriorly for 5 to 7.5 cm lateral to the zygomatic arch while injecting lidocaine

c. If the upper lid is involved in the surgical procedure, make a line of infiltration with local anesthetic subcutaneously approximately 2.5 cm from the margin of the lid

G. Advantages
1. Technique is useful for surgery of the cornea, enucleation of the eyeball, and removal of tumors from the eye and eyelids
2. Technique is quick, safe, and effective if done properly
3. Less edema and inflammation result than when the eyelids and the orbit are infiltrated
4. Surgery of the cornea (removal of tumors and dermoids) can be done easily without retraction or fixation forceps if the eyeball is proptosed
5. Peterson eye block is safer than retrobulbar injections of local anesthetic, which often lead to orbital hemorrhage, direct pressure on the globe, penetration of the globe, damage to the optic nerve, or injection into the optic nerve meninges

H. Disadvantages
1. Technique is difficult
2. The cow's head is difficult to keep horizontal when the animal is in a chute or stanchion with the head tied to one side; this makes the landmarks difficult to locate
3. If the needle point strikes the pterygoid crest, the anesthetic drug will be deposited at the wrong site; therefore no anesthesia results after injection of the local anesthetic
4. In 50% of cases incomplete anesthesia of the upper eyelid results because of sensory innervation from other nerves
5. Blinking is prevented for several hours
6. Sterile saline solution should be applied to the eye frequently during surgery to keep the cornea moist
7. Antibiotic eye ointments should be applied to the cornea after orbital replacement of the globe
8. Sunlight, dust, and wind in the eye must be avoided to prevent keratoconjunctivitis
9. The lids may be sutured together until motor activity of the lids returns

I. Complications
1. In procedures other than enucleation, keratitis may result from postoperative drying of the cornea because effective block prevents blinking for several hours

2. Penetration of the turbinates and injection with local anesthetic into the nasopharynx and optic nerve meninges can cause severe central nervous system toxicity, including certain clinical signs:
   a. Hyperexcitability
   b. Lateral recumbency
   c. Tonic-clonic convulsions
   d. Opisthotonus
   e. Respiratory arrest
   f. Cardiac arrest

Local Anesthesia for the Foot: Three Methods

I. Infiltrating the tissues around the limb with local anesthetic solution (ring block)

II. Desensitizing specific nerves (regional anesthesia)
   A. Brachial plexus block
   B. Epidural anesthesia

III. Injecting local anesthetic solution into an accessible superficial vein in an extremity isolated from circulation by placing a tourniquet on an animal's leg (intravenous regional anesthesia)
   A. Area blocked: extremity distal to tourniquet
   B. Veins used: *A,* Common dorsal metacarpal vein; *B,* radial vein; *C,* plantar metacarpal vein in the thoracic limb; *D,* cranial branch of the lateral saphenous vein, lateral plantar digital vein in the pelvic limb (Fig. 5-12)
   C. Needle: 20- to 22-gauge, 2.54- to 3.81-cm
   D. Anesthetic: 10 to 30 mL of 2% lidocaine (without epinephrine) in adult cattle; 3 to 10 mL lidocaine in small ruminants and pigs
   E. Method: place rubber tourniquet (inflation pressure >200 mm Hg) proximal to the metatarsal or metacarpal region for foot surgery or at a more proximal position for surgery of the carpal or tarsal region; rapidly inject local anesthetic into the prominent vein, directing the needle either proximally or distally
   F. Advantages
      1. Technique is simple and safe
      2. Can be used for the analgesia of the digit in cattle, small ruminants, and pigs; ideal for digital surgery because the amount of bleeding at the surgical site is decreased
      3. No special skill or knowledge of anatomy of the limb is needed

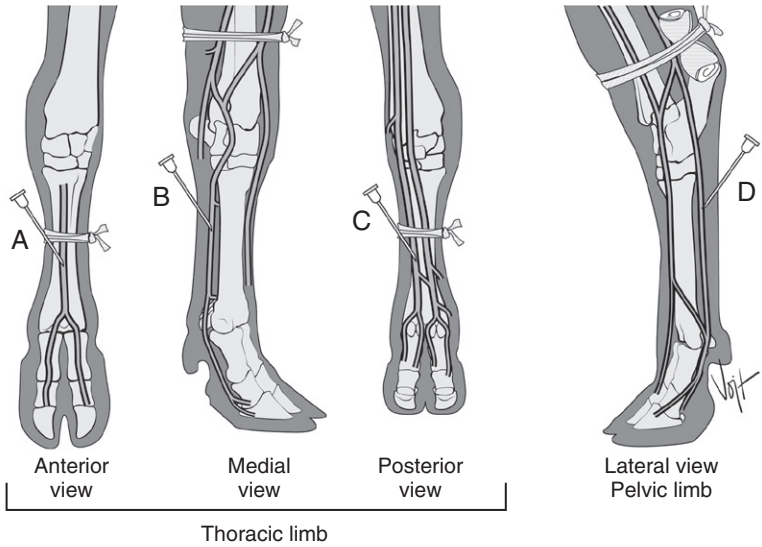


FIG. 5-12. Intravenous regional anesthesia: Tourniquet and needle placement for intravenous regional anesthesia of the cow. The needle tip is placed at (**A**) the common dorsal metacarpal vein, (**B**) the radial vein, or (**C**) the plantar metacarpal vein in the thoracic limb. The needle tip is placed at (**D**) the cranial branch of the lateral saphenous vein in the pelvic limb.

4. Only one injection is required, with little risk of introducing bacteria
5. Onset of anesthesia distal to the tourniquet is rapid (5 to 10 minutes); anesthesia occurs last in the interdigital region
6. Recovery is rapid after removal of the tourniquet (5 to 10 minutes)

G. Disadvantages
1. Inexplicable 7% failure rate
2. Occasional hematoma at the injection site
3. Failure of anesthesia caused by tourniquet slipping or extravascular injection
4. Duration of anesthesia is limited to the time the tourniquet is in place (no residual effect)

H. Complications: ischemic necrosis, severe lameness, and edema if the tourniquet is left in place longer than 2 hours

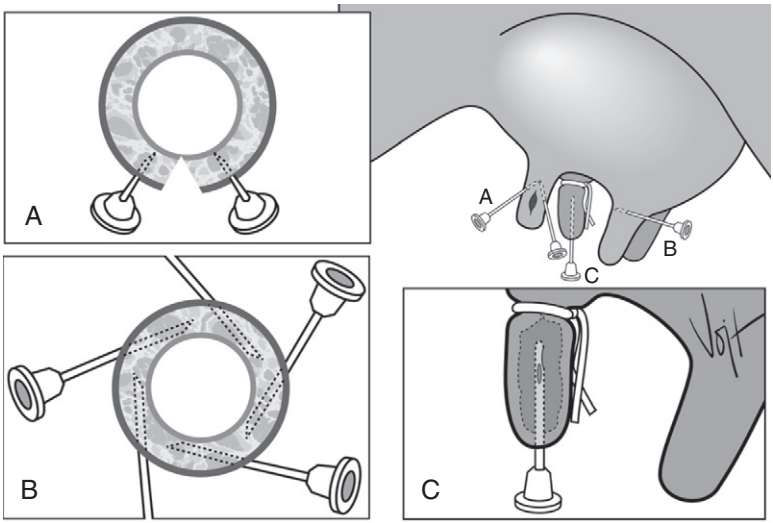


FIG. 5-13. Needle placement in the cow's teat. **A,** Inverted V block. **B,** Teat ring block. **C,** Tourniquet and cannula placement for teat cistern infusion.

Teat and Udder Anesthesia of Cattle

I. Techniques for surgical procedures on the forequarters and foreteats
- A. Paravertebral anesthesia of L1, L2, and L3 spinal nerves
- B. Segmental lumbar epidural anesthesia of L1, L2, and L3 spinal nerves
- C. Both techniques are difficult and often result in cows lying down

II. Techniques for surgical procedures of the caudal-most teats and escutcheon areas of the udder
- A. Desensitization of the perineal nerve in the standing cow
- B. High caudal epidural anesthesia in recumbent ruminants
- C. Lumbosacral epidural anesthesia in recumbent ruminants

III. Most surgical procedures on the teat (e.g., repair of a stenotic teat sphincter, repairs of teat fistulae, lacerations, and injuries) are generally performed with the animal under local anesthesia
- A. Needle: 25-gauge, 1.3-cm or teat cannula
- B. Anesthetic: 4 to 10 mL of 2% lidocaine
- C. Methods
  1. Inverted V block: line infusion of the anesthetic using an inverted V pattern, which encloses the teat skin defect (Fig. 5-13, *A*)

2. Ring block: local anesthetic infused into the skin and muscular tissue of base of the teat, after thorough cleaning of the external surface of the teat and quarter (Fig. 5-13, *B*)
3. Teat infusion block
   a. Teat opening is cleaned
   b. Tourniquet is placed at the base of the teat
   c. 10 mL of 2% lidocaine is infused into the teat cistern (Fig. 5-13, *C*)
   d. Mucous membrane of the teat cistern is anesthetized within 5 minutes; the muscular and skin layers remain sensitive; thereafter the remaining lidocaine is milked out, and the tourniquet is removed

Local Anesthesia in Horses

6

"A horse is dangerous at both ends and uncomfortable in the middle."
IAN FLEMING

OVERVIEW

Many diagnostic and surgical procedures can be performed safely and humanely on horses by coupling physical restraint and sedation with surface (topical) anesthesia, infiltration anesthesia, nerve block (regional) anesthesia, or epidural anesthesia. Peripheral nerve blocks, intraarticular and intrabursal injections, and local infiltrations (ring block) are used to diagnose equine lameness and to anesthetize surgical sites. Desensitization of the auriculopalpebral nerve is most frequently used to prevent voluntary closure of the eyelids during examination and treatment of the eye. Although regional anesthesia of the head can be induced by various techniques, the most frequently desensitized nerves are the supraorbital, infraorbital, and mandibular alveolar nerves.

Caudal epidural anesthesia is used to facilitate surgery involving the tail, perineum, anus, rectum, vulva, vagina, and urethra and for symptomatic relief of painful conditions during obstetric manipulations.

Improper injection techniques contribute to inadequate anesthesia. Overdosing potentially leads to more serious complications including ataxia of hindlimbs, hindlimb motor blockade, recumbency, and respiratory depression.

Regional Anesthesia of the Head

I. Anesthesia of the upper eyelid and forehead
- A. Area blocked: upper eyelid except medial and lateral canthi
- B. Nerve blocked: supraorbital (or frontal) nerve
- C. Site: supraorbital foramen (Fig. 6-1, *A*)
- D. Needle: 22- to 25-gauge, 2.54-cm
- E. Anesthetic: 5 mL of 2% lidocaine
- F. Method: palpate the supraorbital foramen approximately 5 to 7 cm above the medial canthus where it perforates the supraorbital process of the frontal bone; insert the needle into the foramen to a depth of 1.5 to 2 cm; inject 2 mL of

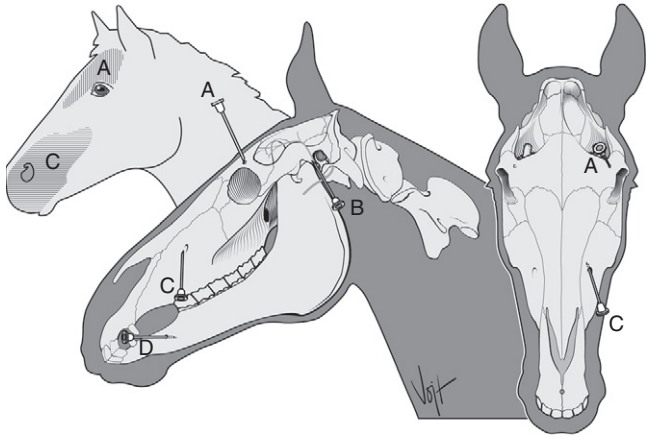


FIG. 6-1. Needle placement for nerve blocks on the head. *A*, Supraorbital (or frontal). *B*, Auriculopalpebral. *C*, Infraorbital. *D*, Mandibular alveolar nerves.

lidocaine into the foramen; 1 mL as the needle is withdrawn and 2 mL subcutaneously over the foramen

G. Use
   1. Desensitizing the upper eyelid
   2. Palpebral motor supply is derived from the auriculopalpebral nerve

II. Akinesia of the eyelids

A. Area blocked: paralysis of orbicularis oculi muscles; no desensitization
B. Nerve blocked: auriculopalpebral nerve (Fig. 6-1, *B*)
C. Site: caudal to posterior ramus of the mandible
D. Needle: 22- to 25-gauge, 2.54-cm
E. Anesthetic: 5 mL of 2% lidocaine
F. Method: insert the needle into the depression caudal to the mandible at the ventral edge of the temporal part of the zygomatic arch; inject local anesthetic subfascially as the needle is withdrawn
G. Use: examining the eye; successful blockade of the motor nerve supply prevents the horse from closing the eyelids

III. Anesthesia of the upper lip and nose

A. Area blocked: upper lip and nostril, roof of nasal cavity, and related skin up to the infraorbital foramen
B. Nerve blocked: infraorbital nerve
C. Site: external opening of the infraorbital canal (Fig. 6-1, *C*)

D. Needle: 20- to 25-gauge, 2.54-cm
E. Anesthetic: 5 mL of 2% lidocaine
F. Method: insertion site is halfway along the bony lip of the infraorbital foramen, about 2.5 cm dorsal to a line connecting the nasomaxillary notch and the rostral end of the facial crest; push upward with the fingertips the flat levator labii superioris muscle, which runs over the foramen, and place the needle tip at the foramen opening
G. Use: treating simple lacerations in quiet or sedated horses

IV. Anesthesia of the lower lip and premolars
A. Area blocked: lower lip, all parts of mandible rostral up to and including the third premolar tooth (PM3)
B. Nerve blocked: mandibular alveolar nerve
C. Site: within mandibular canal (Fig. 6-1, *D*)
D. Needle: 20-gauge, 7.6-cm
E. Anesthetic: 10 mL of 2% lidocaine
F. Method: palpate the lateral border of the mental foramen as a ridge along the lateral aspect of the ramus in the middle of the interdental space; insert the needle into the foramen as far as possible in a ventromedial direction; injection requires pressure, and fluid might partially drain back from the canal under the skin
G. Use: treating simple lacerations in quiet or sedated horses. The technique is difficult, so tooth extraction is better done with the animal under general anesthesia.

V. Caudal epidural anesthesia
A. Area blocked: tail, perineum, anus, rectum, vulva, vagina, urethra, and bladder
B. Nerves blocked: coccygeal and last three pairs of sacral nerves
C. Site: epidural space in the first intercoccygeal space (Co1 to Co2) (Fig. 6-2)
D. Needles: spinal with stylet (spinal: 18-gauge, 5.1- to 7.6-cm)
E. Anesthetic: 6 to 10 mL of 2% lidocaine; other drugs can be considered (see Table 4-2)
F. Method
1. Use proper restraint, depending on the horse's temperament; clip, surgically scrub, and disinfect the injection site; make a skin wheal and infiltrate the tissues down to the interarcuate ligament with 1 to 3 mL of 2% lidocaine to minimize movement while inserting the spinal needle

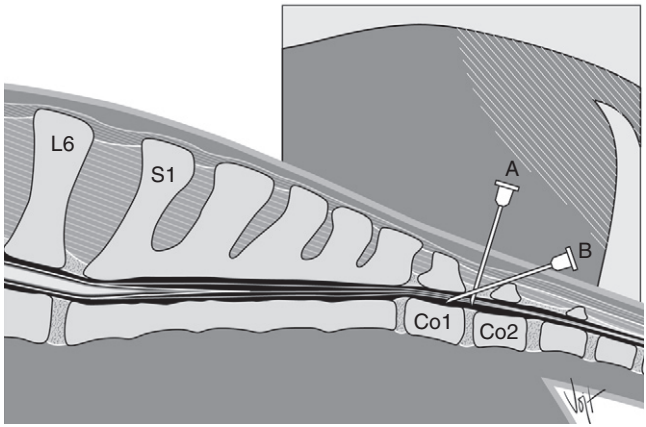


FIG. 6-2. Needle placement into *A* or *B*, caudal epidural space at the first intercoccygeal space (Co1 to Co2). Stippled markings indicate desensitized area after caudal blockade.

2. Method A (see Fig. 6-2, *A*): insert the spinal needle into the epidural space in the center of the first intercoccygeal space (about 5 cm cranial to the origin of the first tail hairs and the caudal fold of the tail) at a right angle to the general contour of the croup and press the needle ventrally in a median plane until it strikes the floor of the vertebral canal; withdraw the needle about 0.5 cm
3. Method B (see Fig. 6-2, *B*): insert the spinal needle about 2.5 cm caudal to the first intercoccygeal space and slide its point ventrocranially at an angle of about 30 degrees to the horizontal plane and to its full length into the vertebral canal
4. Test with a syringe of air for resistance to the injection; alternatively, fill the needle hub with isotonic saline solution and manipulate slightly until the solution is aspirated from the needle by subatmospheric epidural pressure (hanging drop technique); inject local anesthetic; needle can be left in place with stylet reinserted; maximum blockade may require 10 to 30 minutes, and it is not advisable to redose during this time if surgery is to be done with the horse standing

G. Use
1. Anesthesia of pelvic viscera without loss of hind leg motor control during obstetric manipulations

2. Anesthesia of genitalia without loss of hind leg motor control during obstetric manipulations
3. For standing surgical procedures of viscera and genitalia
   a. Caslick procedure (for pneumovagina)
   b. Rectovaginal fistula repair
   c. Prolapsed rectum repair
   d. Urethrostomy
   e. Tail amputation
   f. Tenesmus prevention

H. Common causes for inadequate anesthesia or incomplete block
1. Improper injection technique
   a. Using solutions of diminished potency
   b. Inadequately dispersing anesthetic
2. Inappropriate angulation of the spinal needle
   a. Needle point strikes the dorsal aspect of the vertebral arch
   b. Deviation of the needle from the midline
3. Horses that have fibrous connective tissue from previous epidural injections, which limits diffusion of anesthetic agent
4. Anatomic peculiarities
   a. Presence of septa within the epidural space
   b. Presence of patent intervertebral foramina

I. Potential complications
1. Trauma to coccygeal nerve(s)
2. Infection of the neural canal
3. Extensive cranial migration of local anesthetic solution causing:
   a. Ataxia
   b. Staggering
   c. Excitement
   d. Recumbency

VI. Regional anesthesia of the limb

A. Begin by blocking the most distal branches of the nerve trunks to most effectively localize potential sites of lameness. If lameness is not resolved, continue the examination by injecting local anesthetics more proximally, increasing the size of the desensitized area

B. The palmar (volar) digital nerves of the forelimb or the plantar digital nerves of the hindlimb branch dorsal to the

fetlock at the level of the sesamoids, forming three digital nerves

1. The dorsal digital nerve supplies sensory fibers to the anterior two thirds of the hoof
2. The middle digital nerve (relatively unimportant)
3. The low palmar or plantar digital nerve, which is the most important clinically, supplies sensory fibers to the distal palmar or plantar third of the hoof, including portions, if not all, of the navicular area

VII. Palmar (volar) or plantar digital nerve block (Figs. 6-3, *A,* and 6-4, *A*)

A. Area blocked: distal palmar or plantar third of the foot, including the navicular bursa
B. Nerves blocked: digital nerves
C. Site: palmar (volar)/plantar region of the pastern joint
D. Needle: 20- to 25-gauge, 2.54-cm
E. Anesthetic: 1 to 2 mL of 2% lidocaine at each site
F. Method: palpate the palmar (volar) or plantar nerve just palmar/plantar to the digital vein and artery, dorsal to the flexor tendon; insert the needle in the palmar/plantar region of the pastern joint, medially and/or laterally with the leg elevated or bearing weight
G. Use: diagnosing equine lameness

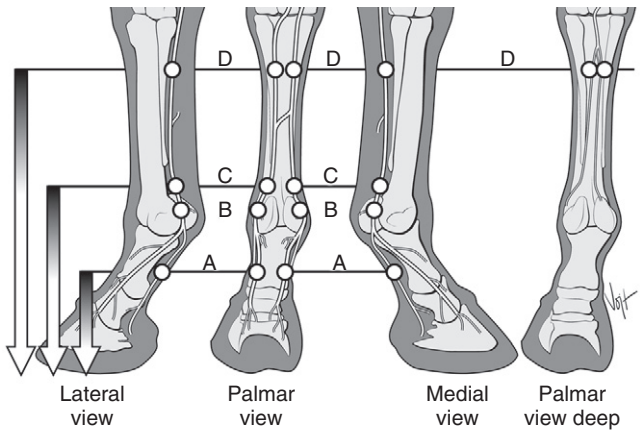


FIG. 6-3. Injection sites for nerve blocks on the left forelimb in the horse. *A*, Palmar (digital). *B*, Abaxial sesamoidean. *C*, Low palmar. *D*, High palmar metacarpal nerves.

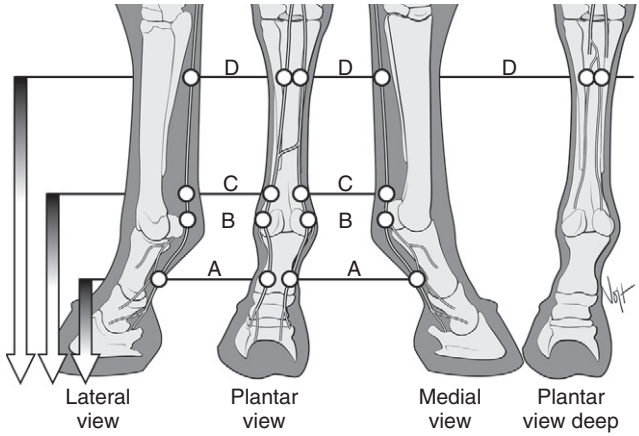


FIG. 6-4. Injection sites for nerve blocks on the left hind limb in the horse. *A*, Plantar digital. *B*, Abaxial sesamoidean. *C*, Low plantar. *D*, High plantar metatarsal nerves.

VIII. Abaxial (basilar) sesamoidean nerve block (Figs. 6-3, *B*, and 6-4, *B*)
- A. Area blocked: entire foot distal to the injection site, including the back of the pastern area and distal sesamoidean ligaments
- B. Nerves blocked: anterior and posterior digital nerves
- C. Site: palmar region of the fetlock joint over abaxial surface of proximal sesamoids
- D. Needle: 20- to 25-gauge, 2.54-cm
- E. Anesthetic: 3 mL of 2% lidocaine at each site
- F. Method: palpate the digital nerve in the palmar region of the fetlock joint over the abaxial surface of proximal sesamoids, just palmar/plantar to the digital artery and vein; insert the needle subcutaneously at this site
- G. Use: diagnosing equine lameness

IX. Palmar (volar) or plantar nerve block
- A. The palmar (volar) or plantar nerves can be desensitized at either a low (distal) site (low palmar/volar or low plantar nerve block) or a high (proximal, below the carpus) site (high palmar/volar or high plantar nerve block)
- B. Midregion blocks (mid-metacarpal or midmetatarsal) should be avoided because of inconsistency of the block due to the location of the anastomotic branch, which traverses downward from medial to lateral

C. Low palmar (volar) or plantar nerve block (Figs. 6-3, *C*, and 6-4, *C*)
   1. Area blocked: almost all structures distal to the fetlock and fetlock joint, except for a small area dorsal to the fetlock joint supplied by sensory fibers of the ulnar (Fig. 6-5) and musculocutaneous nerves (Fig. 6-6)
   2. Nerves blocked: palmar metacarpal or plantar metatarsal nerves (medial/lateral: four-point block)
   3. Site: medially and laterally at the level of the distal enlargements of metacarpals II and IV and metatarsals II and IV (splints)
   4. Needle: 20- to 25-gauge, 2.54-cm
   5. Anesthetic: 2 to 3 mL of 2% lidocaine at each site
   6. Method
      a. Location: just distal to the buttons of the splint bones
      b. Desensitize the palmar nerves (medial/lateral) by injecting the anesthetic between the flexor tendon and suspensory ligament
      c. Desensitize the palmar metacarpal and metatarsal nerves (medial/lateral) by injecting the anesthetic between the suspensory ligament and the splint bone
      d. Use: diagnosing equine lameness

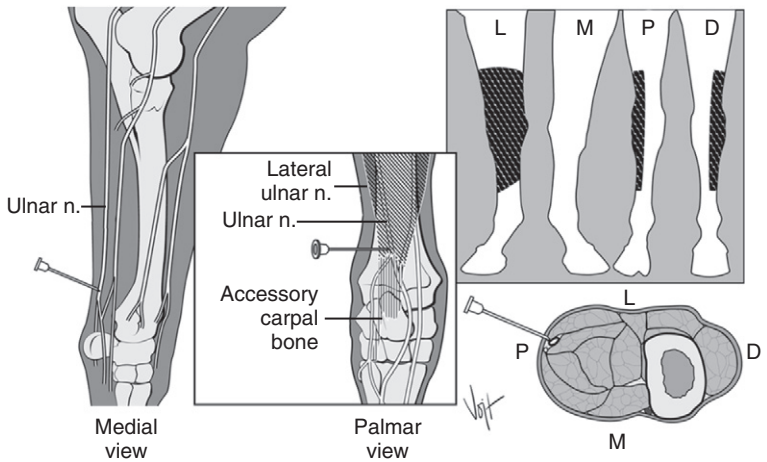


FIG. 6-5. Needle placement for ulnar nerve block: lateral, palmar, and cross-sectional views. Stippled markings indicate desensitized area after ulnar nerve block of the left forelimb. *D*, Dorsal view; *L*, lateral view; *M*, medial view; *P*, palmar view.

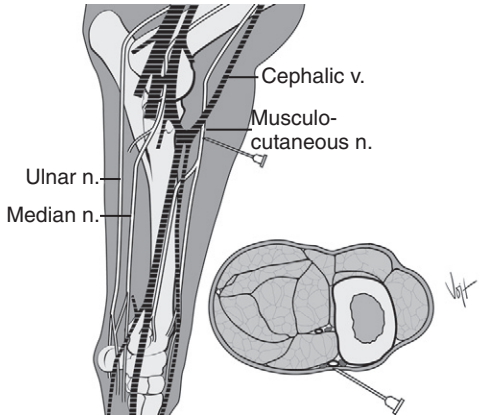


FIG. 6-6. Needle placement for median nerve block: medial and cross-sectional views. Stippled markings indicate desensitized area after median nerve block of the left forelimb. *D*, Dorsal view; *L*, lateral view; *M*, medial view; *P*, palmar view.

D. High palmar (volar) or plantar nerve block (Figs. 6-3, *D*, and 6-4, *D*)
   1. Area blocked: palmar (volar) metacarpal or plantar metatarsal region and the entire digit distal to the fetlock
   2. Nerves blocked: palmar or plantar nerves (medial/lateral)
   3. Site: proximal quarter of the metacarpus or metatarsus proximal to the communicating branch of the medial and lateral palmar (volar) or plantar nerves
   4. Needle: 22-gauge, 3.81-cm
   5. Anesthetic: 5 mL of 2% lidocaine at each site
   6. Method: desensitize the medial and lateral palmar (volar) and plantar nerves by injecting anesthetic subfascially into the groove between the suspensory ligament and the deep flexor tendon on both the medial and lateral sides
   7. Use
      a. Diagnosing equine lameness
      b. The ulnar, median, and musculocutaneous nerves must be desensitized to produce complete anesthesia of the forelimb from the carpus distally

X. Ulnar nerve block (see Fig. 6-5)
   A. Area blocked: lateral or dorsal and palmar skin areas
   B. Nerve blocked: ulnar nerve
   C. Site: 10 cm proximal to the accessory carpal bone
   D. Needle: 22-gauge, 2.54-cm

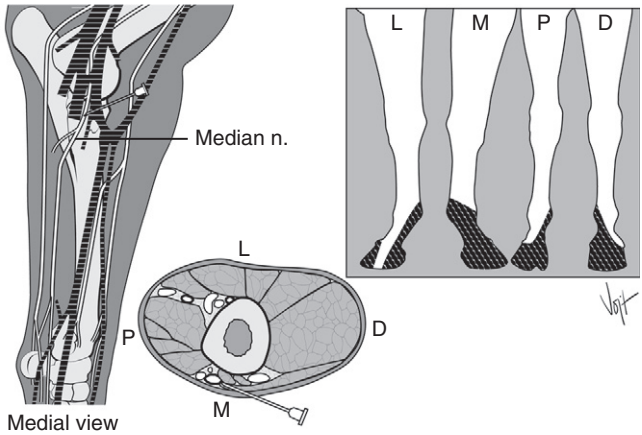


FIG. 6-7. Needle placement for musculocutaneous nerve block: medial and cross-sectional views. Stippled markings indicate desensitized area after musculocutaneous nerve block of the right forelimb. *D*, Dorsal view; *L*, lateral view; *M*, medial view; *P*, palmar view.

E. Anesthetic: 5 to 10 mL of 2% lidocaine
F. Method: the nerve is desensitized 1.5 cm deep beneath the fascia between the flexor carpi ulnaris and ulnaris lateralis muscle
G. Use: anesthetizing part of the forelimb

XI. Median nerve block (Fig. 6-7)
A. Area blocked: lateral, medial, palmar, and dorsal skin areas
B. Nerve blocked: median nerve
C. Site: medial aspect of the forelimb 5 cm ventral to the elbow joint
D. Needle: 20- to 22-gauge, 3.81-cm
E. Anesthetic: 10 mL of 2% lidocaine
F. Method: the median nerve is desensitized between the posterior border of the radius and the muscular belly of the internal flexor carpi radialis
G. Use: anesthetizing part of the distal limb

XII. Musculocutaneous nerve block (see Fig. 6-6)
A. Area blocked: medial, palmar, and dorsal skin areas
B. Nerve blocked: cutaneous branch of the musculocutaneous nerve
C. Site: anteromedial aspect of the forelimb halfway between the elbow and carpus
D. Needle: 22-gauge, 2.54-cm

E. Anesthetic: 10 mL of 2% lidocaine
F. Method: the musculocutaneous nerve is desensitized subcutaneously, where it is easily palpated just cranial to the cephalic vein
G. Use: anesthetizing part of the forelimb

XIII. Intraarticular injections
A. General considerations
1. Clip hair and scrub surgically at site of intraarticular injections to reduce the risk of introducing contaminants
2. Use surgical gloves when performing joint blocks
3. Arthrocentesis implies aspiration of synovial fluid but is usually done to allow for instillation of diagnostic and therapeutic agents
a. Local anesthetic
(1) Adequate amount of local anesthetic should be administered
(2) Enough time should be given for maximal effect and postblock examination
b. Saline flush
c. Antibiotics
d. Hyaluronic acid
e. Antiinflammatory drugs

B. Intraarticular podotrochlear (navicular) bursa block
1. Site: podotrochlear (navicular) bursa (Fig. 6-8, *A*)
2. Needle: 18-gauge spinal needle, 5.1- to 7.6-cm
3. Anesthetic: 2 to 5 mL of 2% lidocaine
4. Method: introduce the needle through the digital pad between the bulbs of the heel at the level of the coronary band until it strikes the bone along the midline while the limb is bearing weight; withdraw the needle until synovial fluid is aspirated, and then inject anesthetic

C. Intraarticular coffin block
1. Site: distal interphalangeal (coffin) joint (P2 to P3) (Fig. 6-8, *B*)
2. Needle: 18- to 20-gauge, 3.8-cm
3. Anesthetic: 5 to 10 mL of 2% lidocaine
4. Method: insert the needle 1.5 cm proximal to the coronary band, approximately 2 cm lateral to the vertical center of the pastern and direct it obliquely ventral to the tendon toward the extensor process

D. Intraarticular pastern block

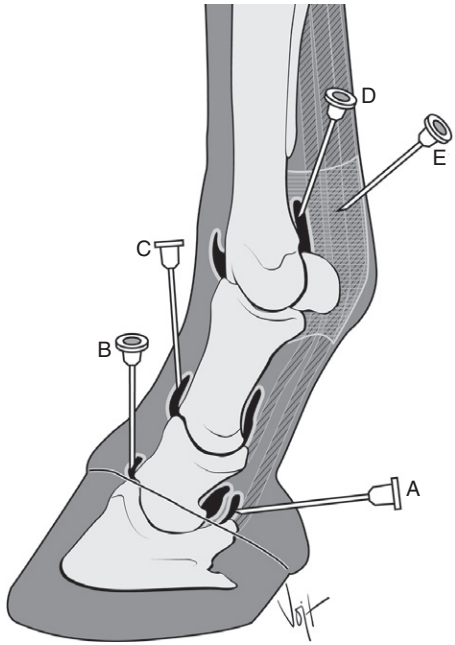


FIG. 6-8. Needle placement for desensitizing: *A*, Podotrochlear (navicular) bursa. *B*, Coffin joint. *C*, Pastern joint. *D*, Fetlock joint. *E*, Distal flexor tendon sheath.

1. Site: proximal interphalangeal (pastern) joint (P1 to P2) (Fig. 6-8, *C*)
2. Needle: 20- to 22-gauge, 3.8-cm
3. Anesthetic: 5 to 8 mL of 2% lidocaine
4. Method: insert the needle medially or laterally to the midline on the palpable epicondyles of P2 for about 2.5 cm in a vertical direction

E. Intraarticular fetlock block
1. Site: metacarpophalangeal or metatarsophalangeal (fetlock) joint (Fig. 6-8, *D*)
2. Needle: 20- to 22-gauge needle, 3.8-cm
3. Anesthetic: 5 to 10 mL of 2% lidocaine
4. Method: insert the needle into the lateral pouch distal to the splint bone and dorsal to the annular ligament of the fetlock to a depth of about 0.5 to 1 cm

F. Digital flexor tendon sheath block
1. Site: digital flexor tendon sheath (Fig. 6-8, *E*)
2. Needle: 18- to 20-gauge, 3.8-cm
3. Anesthetic: 10 mL of 2% lidocaine

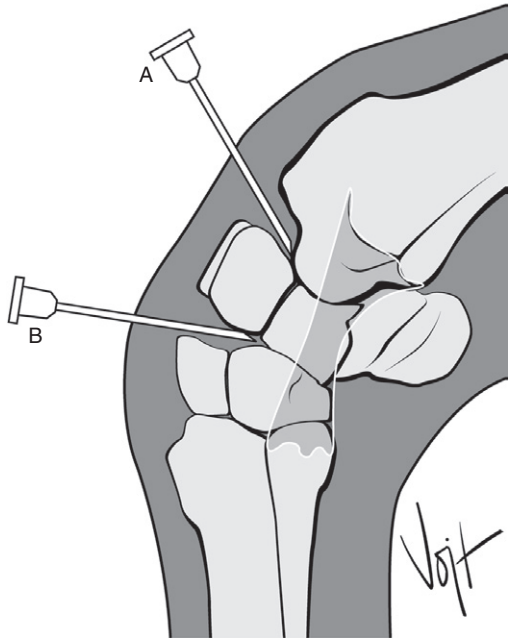


FIG. 6-9. Needle placement for desensitizing: *A*, Radial carpal joint spaces. *B*, Intercarpal joint spaces.

4. Method: insert the needle at the distal end of the splint (button), either medially or laterally, cranial to the deep and superficial flexor tendons and caudal to the suspensory ligament

G. Intraarticular radiocarpal block
1. Site: radial carpal (antebrachial carpal) joint (Fig. 6-9, *A*)
2. Needle: 20-gauge, 3.8-cm
3. Anesthetic: 5 to 10 mL of 2% lidocaine
4. Method: with the carpus flexed, insert the needle between the radiocarpal joint space on either side of the palpable extensor carpi radialis tendon

H. Intraarticular intercarpal block
1. Site: intercarpal (middle carpal) joint (Fig. 6-9, *B*)
2. Needle: 20-gauge, 3.8-cm
3. Anesthetic: 5 to 10 mL of 2% lidocaine
4. Method: with the carpus flexed, insert the needle between the intercarpal joint space on either side of the palpable extensor carpi radialis tendon

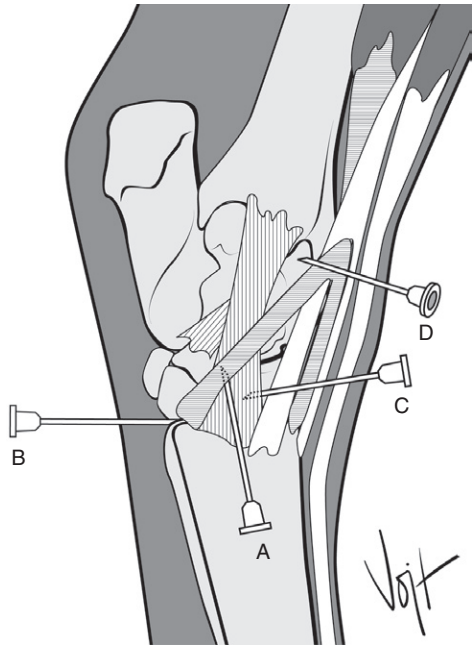


FIG. 6-10. Needle placement for desensitizing: *A*, Cunean bursa. *B*, The tarsometatarsal joint spaces. *C*, Intertarsal joint spaces. *D*, Tibiotarsal joint spaces.

I. Cunean bursa block
   1. Site: cunean bursa on the medial aspect of the tarsus (Fig. 6-10, *A*)
   2. Needle: 22-gauge, 2.54-cm
   3. Anesthetic: at least 10 mL of 2% lidocaine
   4. Method: insert the needle about 1.5 cm distal to the cunean tendon (medial branch of the cranial tibial muscle) and advance it between the cunean tendon and the tarsal bone to penetrate the bursa distally; at least 20 minutes is required for maximum anesthetic effect

J. Intraarticular tarsometatarsal block
   1. Site: tarsometatarsal joint at the caudal lateral aspect of the hock over the lateral head of the splint (metatarsal IV) (Fig. 6-10, *B*)
   2. Needle: 22-gauge, 2.54-cm
   3. Anesthetic: 6 to 8 mL of 2% lidocaine
   4. Method: the needle is most easily inserted into the tarsometatarsal joint on the caudal lateral aspect of the

hock proximal to the palpable lateral head of the splint; the bevel of the needle must be turned away from the bone to allow injection of the anesthetic solution

K. Intraarticular intertarsal block
   1. Site: distal intertarsal joint on the medial aspect of the tarsus (Fig. 6-10, *C*)
   2. Needle: 22-gauge, 2.54-cm
   3. Anesthetic: 6 mL of 2% lidocaine
   4. Method: insert the needle into the joint at a right angle to the skin ventral to the cunean tendon; inject local anesthetic using considerable pressure while turning the needle bevel

L. Intraarticular tibiotarsal block
   1. Site: tibiotarsal (tarsocrural) joint at the craniomedial aspect of the tibia (Fig. 6-10, *D*)
   2. Needle: 18-gauge, 3.8-cm
   3. Anesthetic: 15 mL of 2% lidocaine
   4. Method: the needle is easily inserted less than 2 cm deep into the skin and superficial capsule, 2 to 3 cm ventral to the medial malleolus of the tibia on either the medial or lateral side of the saphenous vein; inject local anesthetic after synovial fluid is recovered on aspiration

7 Local Anesthesia in Dogs and Cats

"Think globally, act locally."
OLIVER WENDELL HOLMES, JR.

OVERVIEW

Local anesthetic techniques can be used in small animals to perform medical and surgical procedures while avoiding the depressant effects of general anesthesia. Local anesthesia is usually administered in combination with sedation or tranquilization to produce a pain-free, cooperative patient. Local analgesic techniques can also be used to produce postoperative analgesia in animals undergoing general anesthesia and surgery. Ultrasound-guided techniques can be used to identify nerves, reduce the total amount of local anesthetic required to produce a nerve block, and improve safety. Commonly used techniques in small animals include infiltration anesthesia, selected nerve blocks, brachial plexus block, intravenous (IV) regional anesthesia, and continuous epidural anesthesia. Epidural opioid, α_2-agonist, or ketamine analgesia; intercostal nerve blocks; and intrapleural analgesia can provide longer-lasting postoperative pain relief (up to 12 hours from a single injection).

Regional Anesthesia of the Head

I. Anesthesia of the upper lip and nose
- A. Area blocked: upper lip and nose, roof of nasal cavity, and related skin ventral to the infraorbital foramen
- B. Nerve blocked: infraorbital
- C. Site: point of emergence of the nerve from the infraorbital canal (Figs. 7-1, *A*, and 7-2, *A*)
- D. Needle: 22- to 25-gauge, 2.5- to 5-cm
- E. Anesthetic: Use 1-2 ml of the chosen anesthetic or anesthetic combination. Do not exceed 1.5 mg of lidocaine/kg of body weight with or without 1.5 mg of bupivacaine or ropivacaine/kg
- F. Method: insert the needle either intraorally or extraorally about 1 cm cranial to the bony lip of the infraorbital foramen; advance the needle to the infraorbital foramen,

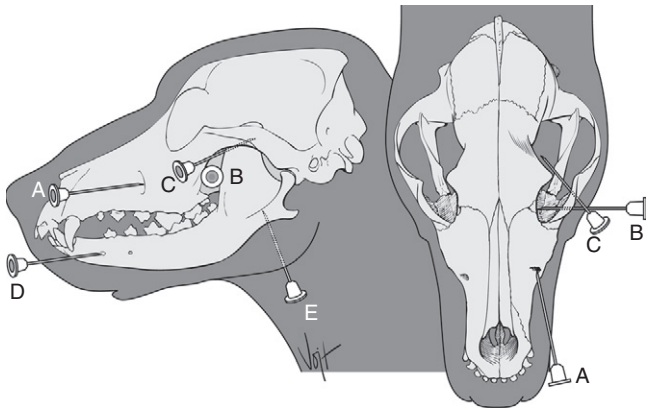


FIG. 7-1. Needle placement for nerve blocks on the head in the dog. *A*, Infraorbital. *B*, Maxillary. *C*, Ophthalmic. *D*, Mental. *E*, Mandibular alveolar.

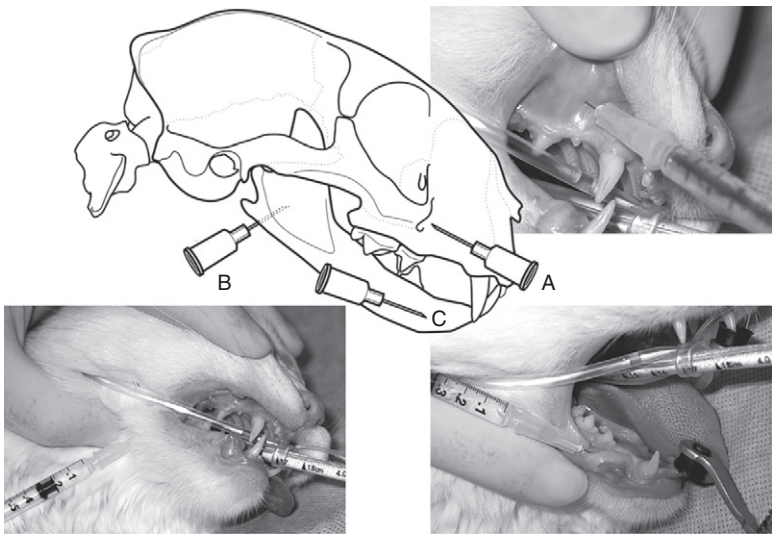


FIG. 7-2. Needle placement for nerve blocks on the head in the cat. *A*, Mandibular alveolar. *B*, Mental. *C*, Infraorbital.

which can be felt between the dorsal border of the zygomatic process and the gingiva of the canine tooth

II. Anesthesia of maxilla, upper teeth, nose, and upper lip
- A. Area blocked: maxilla, upper teeth, nose, and upper lip
- B. Nerve blocked: maxillary

C. Site: perpendicular portion of the palatine bone between the maxillary foramen and foramen rotundum (Figs. 7-1, *B*, and 7-2, *B*)
D. Needle: 22- to 25-gauge, 2.5- to 5-cm
E. Anesthetic: 1-2 ml of the chosen anesthetic or anesthetic combination. Do not exceed 1.5 mg of lidocaine/kg with or without 1.5 mg of bupivacaine or ropivacaine/kg
F. Method: insert the needle through the skin at a 90-degree angle, in a medial direction, ventral to the border of the zygomatic process and about 0.5 cm caudal to the lateral canthus of the eye; advance the needle in close proximity to the pterygopalatine fossa; local anesthetic is administered where the maxillary nerve courses perpendicular to the palatine bone between the maxillary foramen and foramen rotundum

III. Anesthesia of the eye
A. Area blocked: eye, orbit, conjunctiva, eyelids, and forehead skin
B. Nerves blocked: lacrimal, zygomatic, and ophthalmic (i.e., ophthalmic division of the trigeminal nerve)
C. Site: at the orbital fissure (Figs. 7-1, *C*, and 7-2, *C*)
D. Needle: 22- to 25-gauge, 2.5-cm
E. Anesthetic: 1-2 ml of the chosen anesthetic or anesthetic combination . Do not exceed 1.5 mg of lidocaine/kg with or without 1.5 mg of bupivacaine or ropivacaine/kg
F. Method: insert the needle ventral to the border of the zygomatic process at the lateral canthus of the eye; the needle point should be about 0.5 cm cranial to the anterior border of the vertical portion of the ramus of the mandible; advance the needle medial to the ramus of the mandible in a mediodorsal and somewhat caudal direction until it reaches the orbital fissure

IV. Anesthesia of the lower lip
A. Area blocked: lower lip
B. Nerve blocked: mental
C. Site: rostral to the mental foramen (Figs. 7-1, *D*, and 7-2, *D*)
D. Needle: 22- to 25-gauge, 2.5-cm
E. Anesthetic: 0.5-1 ml of the chosen anesthetic or anesthetic combination. Do not exceed 1.5 mg of lidocaine/kg with or without 1.5 mg of bupivacaine or ropivacaine/kg
F. Method: insert the needle over the mental nerve, rostral to the middle mental foramen at the level of the lower second premolar tooth

V. Anesthesia of the mandible and lower teeth
   A. Area blocked: cheek teeth, canine, incisors, skin, and mucosa of the chin and lower lip
   B. Nerve blocked: inferior alveolar branch of the mandibular nerve
   C. Site: point of entry of the nerve into the mandibular canal at the mandibular foramen (Figs. 7-1, *D*, and 7-2, *C*)
   D. Needle used: 22- to 25-gauge, 2.5-cm
   E. Anesthetic: 1-2 ml of the chosen anesthetic or anesthetic combination. Do not exceed 1.5 mg of lidocaine/kg with or without 1.5 mg of bupivacaine or ropivacaine/kg
   F. Method: insert the needle at the lower angle of the jaw about 0.5 cm rostral to the angular process; advance the needle 1.5 cm dorsally against the medial surface of the ramus of the mandible to the palpable lip of the mandibular foramen

Anesthesia of the Foot

I. Anesthesia of the foot may be induced by the following techniques:
   A. Infiltration of the tissues around the limb with local anesthetic solution (ring block) (Fig. 7-3)
   B. Infiltration of the brachial plexus by local anesthetic (brachial plexus block)
   C. IV injection of anesthetic into an accessible superficial vein in a distal extremity that is isolated from circulation by placing a tourniquet on the animal's leg (IV regional anesthesia)
   D. Injection of local anesthetic into the lumbosacral epidural space (anesthesia of the hind legs)
   E. Perineural infiltration of sensory nerves in the limbs (nerve block)

Brachial Plexus Block

I. Area blocked: distal foot, up to the elbow region
II. Nerves blocked: radial, median, ulnar, musculocutaneous, and axillary nerves
III. Site: medial to the shoulder joint (Fig. 7-4)
IV. Needle: 20- to 22-gauge, 7.5-cm (3.7-cm in cats); a spinal needle or catheter stylet works well
V. Anesthetic: 5- 10 ml of the chosen anesthetic or anesthetic combination. Do not exceed 1.5 mg of lidocaine/kg with or without 1.5 mg of bupivacaine or ropivacaine/kg

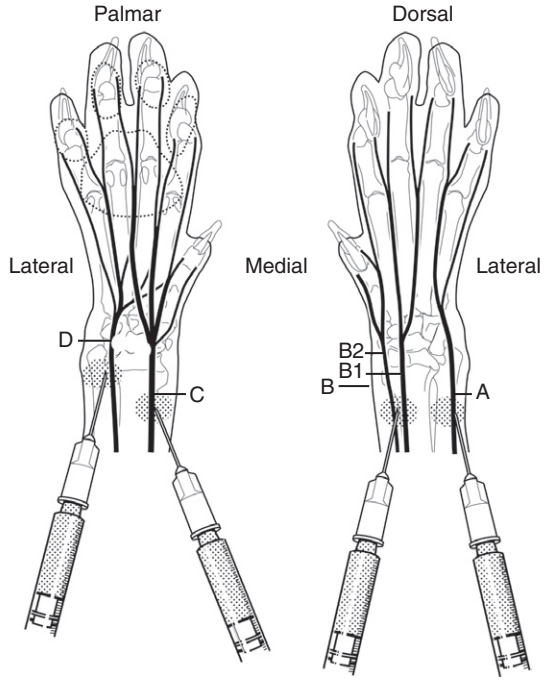


FIG. 7-3. Branches of the ulnar (*A, D*), radial (*B, B1, B2*), and median (*C*) nerves are infiltrated with local anesthetic before a declaw procedure of the front limbs in a cat.

VI. Method:

A. Insert the needle medial to the shoulder joint toward the costochondral junction and parallel to the vertebral column

B. Inject the anesthetic slowly as the needle is withdrawn; anesthesia can be obtained within 20 minutes and for up to 2 hours (total recovery requires about 6 hours)

C. Alternatively, use the same needle placement technique but use a nerve locator and insulated needle

1. The electrodes for the nerve locator controller are connected to the proximal end of the needle (uninsulated area) and the lateral thorax
2. Insert the needle with the nerve locator in the "On" position
3. As the needle gets closer to the brachial plexus, the paw will begin to twitch. The goal is to have a maximum twitch with minimal amperage on the controller.

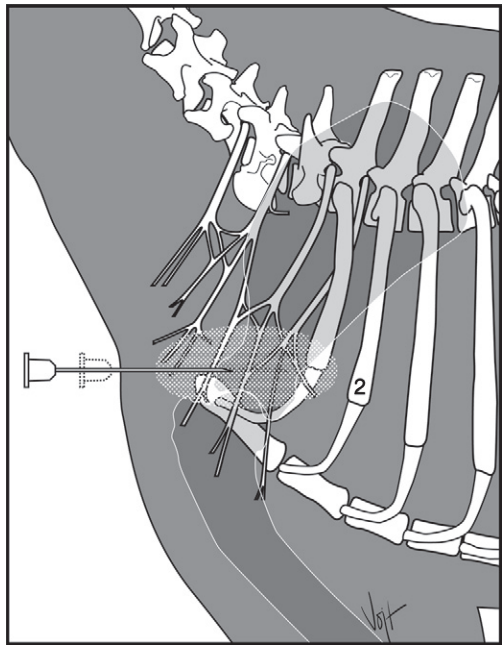


FIG. 7-4. Needle placement for brachial plexus block, lateral aspect of left thoracic limb in the dog.

4. When a maximal twitch is achieved, inject local anesthetic to obliterate the twitch
5. Place the needle at a slightly different angle with the goal of obliterating all twitches in the foot. This will give a 100% block.

D. Advantages
1. Relatively simple and safe to perform
2. Produces selective anesthesia and relaxation of the limb distal to the elbow joint

E. Disadvantages
1. Relatively long waiting period (15 to 30 minutes) required
2. Occasional failure to obtain complete anesthesia, particularly in overweight dogs. This failure is minimized when a nerve locator is utilized.

F. Complications
1. Toxic symptoms after intravascular administration of the local anesthetic
2. Lack of anesthesia after inadvertent intravascular injection



FIG. 7-5. Position of the ultrasound transducer and needle for a midfemoral approach to the sciatic nerve.

Ultrasound Guided Rear Limb Block (sciatic and femoral nerve blocks)

I. Area blocked: The femoral nerve innervates the cranial muscles of the thigh. All remaining muscles of the limb are innervated by the sciatic nerve.

II. Site: The femoral nerve is imaged at the medial aspect of the thigh. The sciatic nerve is imaged just distal and caudal to the greater trochanter.

III. Needle: 22-gauge, 2.5 to 3.7 cm

IV. Anesthetic: 2-4 mL (total) of the chosen anesthetic or anesthetic combination. Do not exceed 1.5 mg of lidocaine/kg with or without 1.5 mg of bupivacaine or ropivacaine/kg

V. Method:

A. Clip the hair from the sacroiliac region just below the stifle on the dorsal, lateral, and medial aspects of the limb

B. Clean the skin and apply coupling gel

C. For the sciatic nerve block, place the dog in lateral recumbency

1. Place the ultrasonic transducer on the transverse plane just distal and caudal to the greater trochanter and then direct it towards the distal aspect of the thigh (Figs. 7-5 and 7-6)
2. The sciatic nerve is imaged from the dorsal aspect. Transverse images can also be obtained by positioning the transducer parallel to the dorsal anatomical plane caudal to the greater trochanter and cranial to the ischiatic tuberosity. Longitudinal images of the sciatic nerve can be

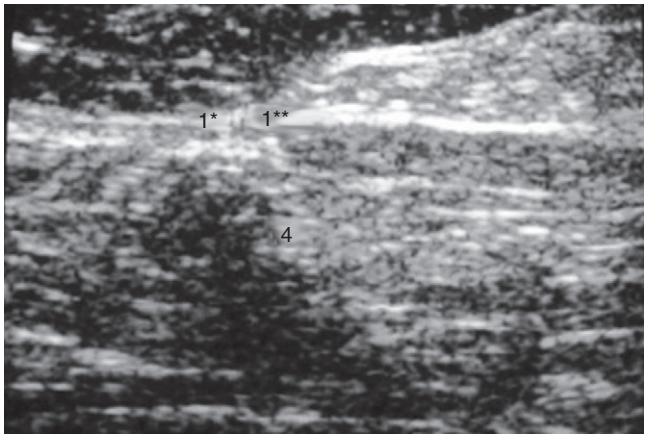


Fig. 7-6. Transverse ultrasound image of sciatic nerve. The two components of the sciatic nerve are readily distinguished and appear as two hypoechoic tubular structures surrounded by a thin hyperechoic rim. (*1**), Peroneus communis nerve; (*1***), tibial nerve; (*4*) adductor magnus muscle.

obtained by rotating the transducer 90 degrees from the position used to obtain the transverse images. Several acoustic windows are available to approach this nerve along the lateral surface of the thigh.

D. Approach of the femoral nerve. This description uses a mid-femur approach. The femoral nerve is imaged at the medial aspect of the thigh. Position the dog in lateral recumbency.
   1. Place the transducer in the inguinal skin crease cranial to the pectineus muscle while the contralateral limb remains abducted (Figs. 7-7 and 7-8). The nerve is scanned cranially to the pectineus muscle. This is the only acoustic window that allows a good approach to the femoral nerve.

E. Both the sciatic and femoral nerves are approached using the acoustic windows described earlier. The accuracy of the nerve location is confirmed by use of a peripheral nerve stimulator.
   1. Connect an insulated needle to the nerve stimulator and insert along the plane of the ultrasound transducer. When the tip is seen close to the nerve, the nerve stimulator is turned on.
   2. When the needle is close to the sciatic nerve, the tarsus should flex or extend. When the needle is close to the femoral nerve, the knee should extend.



FIG. 7-7. Position of the ultrasound transducer for the inguinal approach to the femoral nerve.

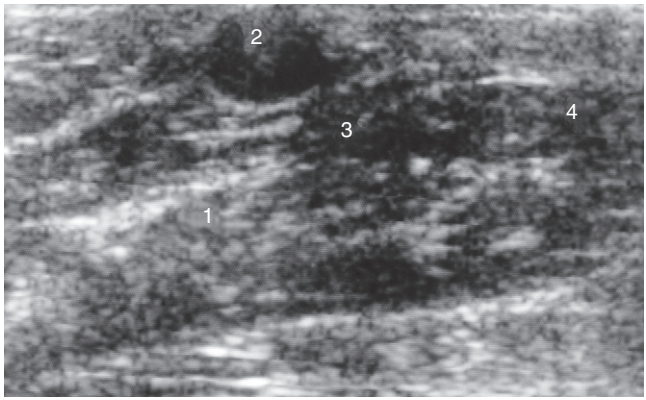


FIG. 7-8. Transverse ultrasound image. (*1*) Femoral nerve; (*2*), femoral artery; (*3*), femoral vein; (*4*) pectineus muscle.

3. Once the nerve is located via ultrasound and confirmed with the nerve–stimulator-induced twitch, inject local anesthetic incrementally to surround the entire nerve. This will look like a donut on the ultrasound image. Usually no more than 0.3 mL of local anesthetic is required to produce a block at each nerve.

F. Advantages: Very high likelihood of complete unilateral limb analgesia

G. Disadvantages: requires ultrasound guidance and a peripheral nerve stimulator

Intravenous Regional Anesthesia (Bier block)

I. Area blocked: extremity distal to tourniquet
II. Nerves blocked: nerve endings in peripheral tissues
III. Site: any superficial vein distal to tourniquet
IV. Needle: 22- to 23-gauge, 2.5-cm; place an IV catheter to ensure
V. Anesthetic: 2.5 to 5 mg/kg of 1% lidocaine (without epinephrine)

NOTE: Do not use bupivacaine for IV regional anesthesia because of the potential for cardiovascular collapse and death

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VI. Method:
- A. First, desanguinate the limb by wrapping it with an Esmarch bandage
- B. Place a rubber tourniquet around the limb just proximal to the elbow for thoracic limb surgery or proximal to the hock for pelvic limb surgery; the tourniquet must be tight enough to exceed blood pressure
- C. Once the tourniquet is secured, unwrap the Esmarch bandage
- D. Inject local anesthetic into any visible vein with light pressure

VII. Advantages
- A. Safe and simple technique
- B. Lack of toxicity to organs if the occlusion of blood supply is limited to 2 hours
- C. Blood-free surgery site is ideal for taking biopsies and removing foreign bodies from the paws

VIII. Disadvantages
- A. Limited to 2 hours
- B. Effect is terminated when the tourniquet is removed

IX. Complications
- A. Shock can occur if tourniquet is left on more than 4 hours (reversible)
- B. Sepsis, endotoxemia, and death can occur if tourniquet is left on more than 8 to 10 hours

Lumbosacral Epidural Anesthesia

I. Indications
- A. Animals that are severely depressed, are in shock, or require immediate surgery of the rear quarters
- B. Animals that are at high risk, are aged, or in which the use of other analgesic or anesthetic agents is contraindicated

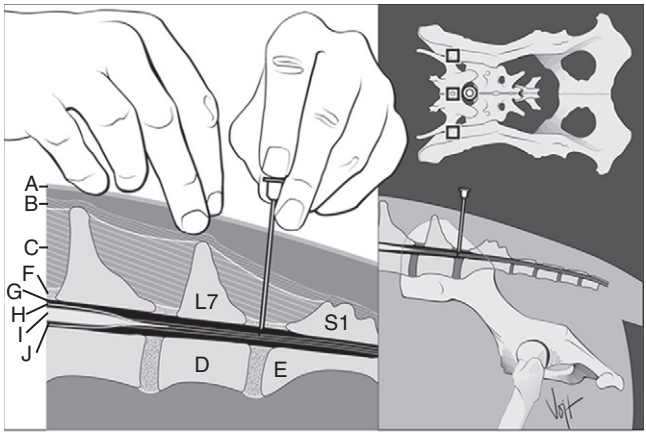


FIG. 7-9. Needle placement for lumbosacral epidural (between L7 and S1) anesthesia in the dog, lateral and dorsal aspects. *A*, Skin; *B*, supraspinous ligament; *C*, interspinous ligament; *D*, seventh lumbar vertebra; *E*, sacrum; *F*, interarcuate ligament (ligamentum flavum); *G*, epidural space; *H*, dura mater spinalis; *I*, spinal cord; *J*, subarachnoid space containing cerebrospinal fluid.

C. Opioids are used to provide analgesia after abdominal surgery or surgery of the rear limbs; paralysis is not produced

II. Specific procedures
- A. Surgery
  1. Tail amputation
  2. Anal sac therapy or perianal surgery
  3. Rear limb lacerations or fractures
  4. Urolithiasis therapy
  5. Abdominal surgery
  6. Cesarean section
  7. Obstetrical manipulations
  8. Surgical procedures of the tail, perineum, vulva, vagina, rectum, and bladder
- B. Postoperative analgesia

III. Landmarks and anatomy (Figs. 7-9 and 7-10)
- A. Right and left cranial dorsal iliac wings of the ilium
- B. Spinous process of the seventh lumbar vertebra and the median sacral crest
- C. Important anatomic features
  1. Shape of lumbar and sacral spinous processes
  2. Interspinous ligament
  3. Ligamentum arcuatum (ligamentum flavum)

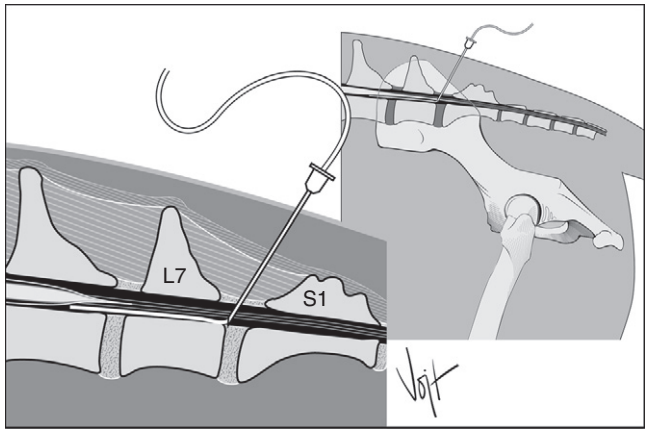


FIG. 7-10. Needle placement for continuous epidural anesthesia in the dog, shown in the lateral aspect. L7 and S1 are the spinous processes of the seventh lumbar and the first sacral vertebrae.

4. Terminal portion of the dural sac
5. Filum terminale
6. Intervertebral disk

D. The spinal cord usually ends at vertebral body L6 to L7 in dogs and L7 to S3 in cats; therefore the procedure is more hazardous when performed on cats

IV. Equipment

A. 18- or 22-gauge, 5- to 10-cm (22-gauge, 2.5- to 3.75-cm in cats), beveled spinal needle with stylet (disposable needle preferred)
B. One 3-mL and one 6-mL syringe
C. A thin-walled, 18-gauge, 7.5-cm needle (Tuohy needle, Crawford needle) is used if a polyethylene catheter is to be placed for continuous epidural anesthesia

V. Procedure

A. Clip and perform a surgical scrub; this is a sterile procedure
B. Place the spinal needle perpendicular to the skin surface at the midline of the lumbosacral space; this space can be palpated halfway between the dorsoiliac wings and just caudal to the dorsal spinous process of the seventh lumbar vertebra (Fig. 7-9)
   1. Infiltration of the area with 2% lidocaine may facilitate placement of the spinal needle

2. Push the spinal needle ventrally in a slight cranial or caudal angle as needed

C. Resistance is encountered when the ligamentum flavum is reached; a distinct "pop" is usually felt when the needle is advanced through this ligament

D. On penetrating the ligamentum flavum, the needle is in the epidural space
   1. Needle depth may vary from 1 to 4 cm, depending on animal size
   2. Remove the stylet and examine the needle for blood or cerebrospinal fluid (CSF); if no blood or CSF is observed, the needle should be aspirated for blood or CSF
   3. Inject 1 to 2 mL of air to check for proper needle placement
      a. If subcutaneous crepitus is felt, the needle is incorrectly placed and should be repositioned
      b. No resistance should be felt to the injection of air or local anesthetic agent

VI. Doses

A. A test dose of 0.5 to 1 mL of 2% lidocaine produces almost immediate dilation of the external anal sphincter, followed by relaxation of the tail and ataxia of pelvic limbs within 3 to 5 minutes

B. The required dose varies depending on the desired effect
   1. 1 mL/4.5 kg of 2% lidocaine or 0.75% bupivacaine; this will produce anesthesia as far cranial as L1
   2. 1 mL/5 kg 2% lidocaine or 0.75% bupivacaine if anesthesia is required up to T5
   3. 1 mL/6 kg of 2% lidocaine or 0.75% bupivacaine; satisfactory for cesarean section

C. Small amounts of 1:200,000 epinephrine can be added to lidocaine to delay the rate of absorption, thus prolonging anesthetic action by 30 minutes (total of 2 hours)

D. Bupivacaine with epinephrine or ropivacaine produces 4- to 6-hour periods of anesthesia

VII. Continuous epidural anesthesia in dogs

A. Procedure
   1. The procedure is similar to that previously described, except that a curved bevel spinal needle (Tuohy) is used, through which a catheter is passed (Fig. 7-10)
   2. The Tuohy needle is inserted into the epidural space with the needle bevel directed cranially

3. Only 2 to 3 cm of catheter should be advanced into the epidural space
4. Withdraw the needle, but leave the catheter in place

B. Advantages
1. Ability to tailor the duration of anesthesia to the length of operation
2. Route for injecting epidural opioids during and after surgery (see epidural opioid analgesia)

C. Disadvantages
1. Technically difficult
2. Potential for damage to the spinal cord, meninges, and nerves
3. Risk of infection
4. Catheter-related problems (e.g., kinks, displacement, clotting with fibrin)

VIII. Factors influencing cranial level of blockade
A. Size of patient
B. Conformation of patient
C. Volume of drug injected
D. Drug mass (volume × concentration)
E. Rate of injection
F. Direction of needle bevel
G. Age of patient
H. Obesity
I. Intraabdominal pressure attributable to presence and size of abdominal mass (e.g., pregnancy)
1. The volume of the epidural space in pregnant animals is decreased because of distention of epidural veins/engorgement
2. Neural tissue sensitivity to drug effects is increased during pregnancy

J. Position of patient: gravity has a more definite role in the spread of subarachnoid anesthesia than in epidural anesthesia
1. With both techniques, a more rapid onset to maximal segmental anesthesia (unilateral anesthesia), a longer duration of anesthesia, and a more intensive motor blockade are achieved in the dependent side than in the upper side

IX. Proposed site of action after epidural injection (Fig. 7-11)

X. Possible complications
A. Injection of local anesthetic into the vertebral sinuses
1. Vomiting, tremors

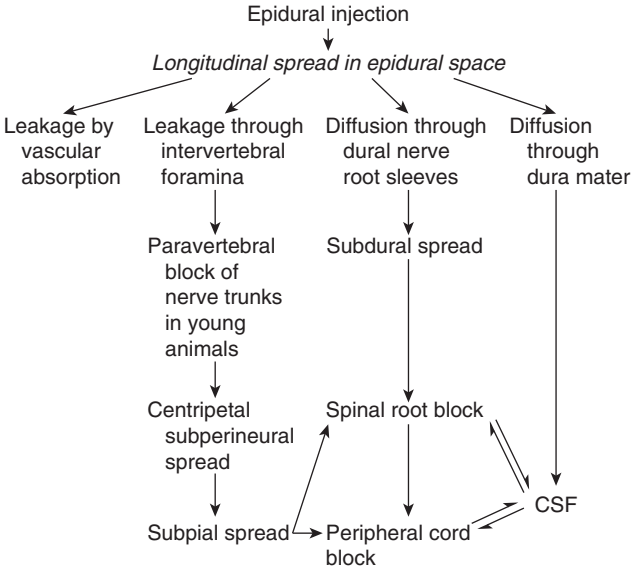


FIG. 7-11. Proposed drug distribution after epidural injection. *CSF*, Cerebrospinal fluid.

2. Decreased blood pressure caused by peripheral vasodilation
3. Convulsions
4. Paralysis
5. Lack of intended effect

B. Respiratory depression and paralysis in dogs and cats caused by drug overdose
   1. The drug must migrate to approximately C5 or C7 to produce complete respiratory paralysis from blockade of the phrenic nerves
   2. The cephalad spread of anesthesia after epidural or subarachnoid injection (of specifically prepared hyperbaric solution [e.g., "heavy Nupercaine"] in 6% glucose) is limited in an animal that is kept in a sitting position

C. Temperature may fall in small animals because they are unable to shiver; the patient's rear quarters should be kept warm by wrapping them in a towel or a heated water blanket

D. Administer a sedative or tranquilizer for patient cooperation

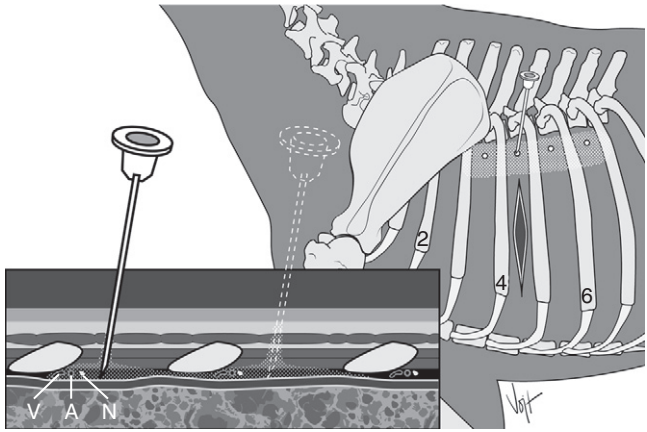


FIG. 7-12. Needle placement for intercostal nerve block in the dog, shown in the lateral aspect and the sagittal section. *2*, *4*, *6* are the second, fourth, and sixth ribs; *VAN*, intercostal vein, artery, and nerve.

Epidural Opioids and α_2-Adrenoceptor or Local Anesthetic Analgesia

I. Indications
- A. Intraoperative analgesia
- B. Postoperative analgesia
- C. Critical care animals

II. Site of opioid injection
- A. Lumbosacral epidural space (single-dose injection) (Figs. 7-9 and 7-10)
- B. Anterior lumbar epidural space (catheter technique) (Fig. 7-12)

III. Drugs
- A. Epidural morphine (0.1 mg/kg diluted in 0.1 to 0.3 mL/kg of 0.9% NaCl solution) produces pain relief 30 to 60 minutes after injection and for as long as 6 to 24 hours
- B. Epidural morphine (0.1 mg/kg) alone or combined with xylazine (0.02 mg/kg) or dexmedetomidine (2 to 5 μg/kg) produces minimal cardiovascular changes in dogs anesthetized with 1.5 minimum alveolar concentration (MAC) of isoflurane
- C. Epidural morphine (0.1 mg/kg) with dexmedetomidine (5 μg/kg) produces pain relief for at least 13 hours

D. Epidural morphine (0.1 mg/kg) with bupivacaine (0.5%, 1 mL/10-cm distance from the occipital protuberance to the lumbosacral space) decreases the isoflurane requirement more and provides longer lasting analgesia (more than 24 hours) than morphine alone (5.5 hours) or bupivacaine alone (9 hours)
E. Epidural oxymorphone (0.05 to 0.1 mg/kg diluted in 0.3 mL/kg of 0.9% NaCl solution) produces pain relief 20 to 40 minutes after injection and for about 10 to 15 hours
F. Epidural fentanyl (1 to 10 μg/kg diluted in 0.2 to 0.3 mL/kg of 0.9% NaCl solution) produces pain relief 15 to 20 minutes after administration, with analgesia lasting 3 to 5 hours
G. Epidural fentanyl (1 – 10 μg/kg) with lidocaine (0.3 mL/kg, 2% solution 1:200,000 epinephrine) produces scrotal anesthesia in 2 minutes after administration, with anesthesia lasting 2 to 2.5 hours
H. Epidural xylazine (0.05 to 0.3 mg/kg) decreases the isoflurane requirement in a dose-dependent manner and is associated with few cardiopulmonary effects in anesthetized dogs
I. Epidural dexmedetomidine (15 μg/kg, diluted in 0.1 mL/kg of 0.9% NaCl solution) produces pain relief for 7 hours in dogs
J. Epidural dexmedetomidine (10 μg/kg) increases the pain threshold for the hindlimb for 20 to 240 minutes after administration and for the forelimb for 15 to 120 minutes after administration; mild sedation can occur; occasional emesis in cats

IV. Advantages
A. Small doses produce relief of somatic and visceral pain that is more profound and prolonged than that produced by comparable parenterally administered (IM, IV) opioids with less sedation
B. No interference with sensory function
C. No interference with motor function
D. Minimal depression of the sympathetic nervous system
E. Modification of the endocrine-metabolic stress response, improvement in pulmonary function, decreased morbidity, and a comparatively short recovery
F. Reversal of side effects by low-dose IV infusion of opioid antagonists (e.g., naloxone)

V. Potential side effects (rare)
A. Respiratory depression
B. Urinary retention

C. Delayed gastrointestinal motility
D. Vomiting
E. Pruritus

VI. Complications
A. Respiratory depression after large doses (>1 mg/kg) of epidural morphine
B. Catheter-related problems
1. Catheter displacement
2. Occlusion
3. Infection

Epidural Ketamine Analgesia

I. Mechanism of action
A. The precise mechanism of analgesic action after epidural or subarachnoid administration of ketamine has not been clearly defined
B. Ketamine may act as an antagonist at the *N*-methyl-D-aspartate receptors, preventing the development of neural changes involved in hyperesthesia
C. *N*-methyl-D-aspartate receptors play an important role in spinal neural plasticity, such as central sensitization, wind-up, and hyperalgesia
D. Ketamine may possess some δ opiate agonist activity in addition to being a phencyclidine agonist

II. Indications
A. Preemptive (postoperative) analgesia when administered epidurally in the preoperative period
B. Intraoperative analgesia lessens the cardiovascular depressant effects of inhalant anesthesia as a result of MAC-sparing effect
C. Postoperative analgesia with minimal respiratory depression and cardiovascular changes (e.g., blood pressure, heart rate)

III. Method
A. Epidural ketamine (2 mg/kg, diluted to a volume of 1 mL of sterile 0.9% NaCl/4.5 kg) produces analgesia for 2 hours
B. Epidural ketamine (1 mg/kg) can provide pain relief with few cardiopulmonary effects but with occasional salivation
C. Epidural ketamine (0.5 mg/kg or 1 mg/kg) combined with morphine (0.05 mg/kg or 0.025 mg/kg) can provide pain relief with few cardiopulmonary effects and sedation; ketamine (1 mg/kg) combined with morphine (0.025 mg/kg) may produce salivation

D. Epidural meperidine may interact antagonistically rather than synergistically with epidural ketamine

IV. Advantages
- A. Local anesthetic effects
- B. Alternative method to epidural opioid administration in dogs anesthetized with isoflurane or sevoflurane
- C. Minimal changes in cardiovascular parameters such as heart rate, blood pressure, central venous pressure, cardiac index, systemic and pulmonary vascular resistance, and rate-pressured product in isoflurane-anesthetized dogs (MAC 1.2% to 1.6%)

V. Potential side effects
- A. Differences in the analgesic response to epidurally administered ketamine have been observed; attributable to anatomic differences, dose regimen, and inhalant anesthesia

VI. Multimodal epidural drug combination
- A. Epidural: Dexmedetomidine (5 μ/kg); ketamine (50 to 100 μg/kg); morphine (0.1 mg/kg); bupivacaine (0.25 to 0.5 mg/kg) drug combination
  1. Multimodal drug combinations for epidural use can produce more effective and prolonged effects than single drug use but most drug combinations have not been clinically validated

Intra-articular Bupivacaine or Morphine

I. Indication: local analgesia for stifle, elbow, hock, and more distal joints

II. Method: an intraarticular injection of bupivacaine or morphine is given after surgery (e.g., surgical repair of ruptured cranial cruciate ligaments) and before skin closure
- A. 0.5 mL of bupivacaine HCl (0.5%)/kg or 0.1 mg morphine (preservative-free morphine, Duramorph, or Astramorph) diluted with 0.9% NaCl to a volume of 0.1 mg/kg

III. Results
- A. Intraarticular bupivacaine and morphine provide postoperative analgesia without adverse reactions
- B. Intraarticular bupivacaine produces the greatest local anesthetic effect, lasting up to 24 hours after administration, allowing dogs to recover completely while alert
- C. Intraarticular morphine provides some analgesia lasting at least 6 hours, but not to the extent of intraarticular bupivacaine

D. Intraarticular morphine provides effective analgesia comparable to epidural morphine (0.1 mg/kg) in dogs
E. Inflammation is needed for morphine to produce its antinociceptive effect; inflammation may cause activation of receptors already present within peripheral tissues

IV. Advantages
A. Easy to perform
B. Local analgesia provides pain relief without the need for systemic administration of analgesic/sedative drugs, allowing systemic functions to be undisturbed
C. Local analgesia allows local inflammation to proceed while providing symptomatic relief of pain

Intercostal Nerve Blocks

I. Indications
A. Relief of pain during thoracotomy
B. Analgesia after thoracotomy
C. Pleural drainage
D. Rib fractures

II. Nerves blocked: intercostals both cranial and caudal to the incision or injury site because of overlap of nerve supply

III. Site: a minimum of two adjacent intercostal spaces near the intercostal foramen (see Fig. 7-12)

IV. Needle: 22- to 25-gauge, 2.5-cm

V. Anesthetic: 0.25 to 1 mL of 0.25% or 0.5% bupivacaine, or 0.2% or 0.5% ropivacaine/site, with or without epinephrine 1:200,000; total dose should not exceed 3 mg/kg (the technique produces high blood concentrations of the anesthetic)
A. Small dog: 0.25 mL/site
B. Medium dog: 0.5 mL/site
C. Large dog: 1 mL/site

VI. Method: insert the needle through the skin at a 90-degree angle caudal to the rib near the intervertebral foramen; inject small volumes and/or diluted anesthetic solutions into a minimum of two adjacent intercostal spaces

VII. Advantages
A. Selective intercostal nerve block is easily performed because of the proximity of each nerve to its adjacent rib
B. The intercostal nerves can be visualized beneath the pleura during thoracotomy
C. The technique provides consistent analgesia for 3 to 6 hours without respiratory depression

VIII. Complications
- A. Pneumothorax after faulty technique
- B. Impaired blood-gas exchange (hypercarbia, hypoxemia) in dogs with pulmonary diseases if ventilatory efforts are reduced

Intrapleural Regional Analgesia

I. Indications
- A. Relief of pain originating from the following conditions:
  1. Thoracotomy
  2. Rib fractures
  3. Mastectomy
  4. Chronic pancreatitis
  5. Cholecystectomy
  6. Renal surgery
  7. Abdominal cancer
  8. Metastasis of the chest wall, pleura, and mediastinum

II. Nerves blocked: mechanisms of pain relief are not fully understood
- A. Retrograde diffusion of local anesthetic through the parietal pleura, causing intercostal nerve block
- B. Desensitization of the thoracic sympathetic chain and splanchnic nerves

III. Site: place a catheter into the pleural space either percutaneously or before closure of a thoracotomy (Fig. 7-13)

IV. Equipment: 17-gauge, 5-cm, Huber-point (Tuohy) needle; medical grade silastic tubing, 5 to 10 cm, 2 mm inside diameter; sterile sets for single, continuous interpleural analgesia are available

V. Anesthetic: approximately 1 to 2 mg of 0.5% bupivacaine/kg or 0.2% ropivacaine/kg (0.5%, with or without 1:200,000 epinephrine)

VI. Method: in a well-sedated animal, desensitize the skin, subcutaneous tissue, periosteum, and parietal pleura over the caudal border of the rib with 1 to 2 mL of 2% lidocaine, using a 22-gauge, 2.5-cm needle; then use the Huber-point needle to place the catheter with minimal resistance into the subatmospheric pleural space, 3 to 5 cm beyond the needle tip (see Fig. 7-13); withdraw the needle over the catheter and leave the catheter in place; catheter placement in the open chest is accomplished by inserting the Tuohy needle through the skin at least two intercostal spaces caudal to the incision and passing the

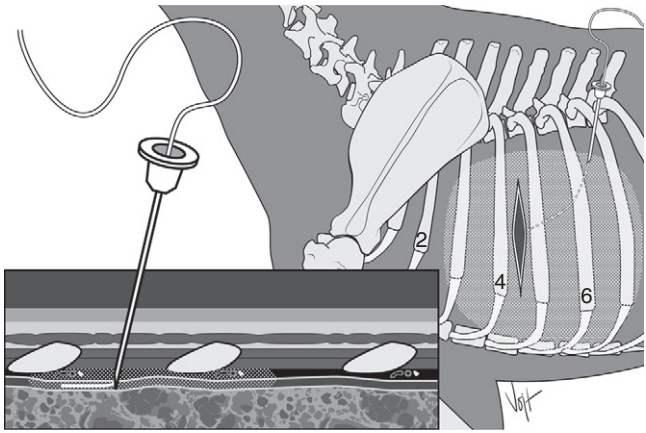


FIG. 7-13. Needle and catheter placement for intrapleural regional analgesia in the dog, shown in the left lateral aspect and the sagittal section. *2*, *4*, *6* are the second, fourth, and sixth ribs.

catheter through the needle subpleurally under direct vision; inject local anesthetic over 1 to 2 minutes after negative aspiration of air or blood through the catheter; then clear the catheter with 2 mL of physiologic saline solution

VII. Advantages
- A. The procedure is simple to perform
- B. One needlestick is needed in contrast to multiple intercostal nerve blocks
- C. Post-thoracotomy pain relief lasts longer (3 to 12 hours) than analgesia produced by subcutaneous morphine (0.5 mg/kg) or selective intercostal nerve blocks with bupivacaine (0.5 mL per site)
- D. Long-term use (over several weeks) of an interpleural catheter is possible

VIII. Complications
- A. Lung trauma
- B. Infection
- C. Phrenic nerve paralysis or paresis; paradoxical respiration with negative intraabdominal pressure
- D. Tachyphylaxis to local anesthetic
- E. High anesthetic blood concentration
- F. Systemic toxicity after excessive doses of the local anesthetic (>3 mg bupivacaine/kg)

G. Catheter-related complications (e.g., pneumothorax)
H. Bleeding
I. Minimal pain relief
J. Misplaced catheter

IX. Limitations (technique is ineffective)
A. Excessive bleeding into the pleural space
B. Pleural effusion

Injectable Anesthetic Drugs

8

"To sleep: perchance to dream."
WILLIAM SHAKESPEARE

OVERVIEW

Injectable, intravenous (IV), and intramuscular (IM) anesthetic drugs can be used to induce immobilization and general anesthesia. Proper use of preanesthetic medication (tranquilizers, sedatives, analgesics) is imperative to produce the optimal desired effect with minimal side effects. Injectable anesthetic drugs are often more convenient and may be less expensive than inhalant drugs. Their principal disadvantage is that once administered, they cannot be controlled and are not immediately eliminated. Several injectable anesthetic drugs (thiopental, methohexital, propofol, etomidate, alphaxalone) have a relatively short duration of action.

General Considerations

I. Increasing intensities of central nervous system (CNS) depression can be produced, ranging from drowsiness and mild sedation to anesthesia and coma

II. Factors that can determine rate of onset, amount of depression, and duration of anesthesia
- A. Potency of anesthetic drug
- B. Dose
- C. Rate of drug administration when administered IV
- D. Route of administration (IV, IM, subcutaneous [SQ], intraperitoneal [IP])
- E. Drug pharmacokinetics and protein binding
  1. Decreased renal function may prolong and intensify drug effects
  2. Decreased hepatic function may prolong and intensify drug effects

3. Decreased plasma protein concentrations may increase the effects of drugs that are highly protein bound (barbiturates)

F. Animal's level of consciousness (excited versus depressed) when the drug is administered
G. Acid-base and electrolyte balance (e.g., acidosis enhances barbiturate anesthesia)
H. Animal's cardiac output and blood flow distribution
I. Drug tolerance (age, breed, obesity)
J. Interactions with other drugs

III. Most injectable anesthetic drugs produce unconsciousness by depressing the CNS
A. Some are used to control seizures (barbiturates; propofol)
B. Barbiturates depress spinal reflexes and can be used clinically for the treatment of strychnine poisoning

IV. Routes of administration
A. Most injectable drugs are administered IV
1. Dissociatives (ketamine; tiletamine-zolazepam) and neurosteroids (alphaxalone) can be administered IV or IM

B. Injectable anesthetic drug diluents can produce side effects
1. The extreme alkalinity of barbiturate solutions (pH 12 to 13), results in necrosis and sloughing if accidentally administered perivascularly; barbiturates should not be injected IM or SC
2. Intralipid, the diluent for propofol, supports bacterial growth and can interfere with some blood chemical tests
3. The pH of the commercially available formulations of ketamine is between 3.5 and 5.5 and is likely responsible for pain on injection when administered IM
4. Etomidate causes perivascular irritation and hemolysis due to high osmolality (4965 mOsmol/L)

V. Doses should be calculated on the basis of lean body mass (body weight minus fat; Table 8-1)

Barbiturate Anesthesia (Discussed for Historical and Comparative Purposes)

I. Barbiturates are categorized according to their duration of action
A. Long: 8 to 12 hours (phenobarbital)
B. Intermediate: 2 to 6 hours
C. Short: 45 to 90 minutes (pentobarbital)
D. Ultrashort: 5 to 15 minutes (thiopental, methohexital)

TABLE 8-1 Intravenous Drugs Commonly Used To Produce Anesthesia of Short Duration (mg/kg)

	Agent	Horse	Dog	Cat	Pig	Cow	Goat
1	Thiopental	up to 7	8-20	8-20	10-20	7-13	4-10
2	Etomidate	—	0.5-2	0.5-2	0.5-2	—	—
3	Propofol	2-8	4-10	3-10	4-13	—	—
4	Alphaxalone	1-3	2-5	2-5	2-5	2-3	2-3
5	Guaifenesin	50-100	40-90	—	40-90	100	100
6	Chloral hydrate	60-200	—	—	6-9 g/45 kg	60-200	60-200
7	Thiopental	4-6	—	—	5.5-11	4-6	—
8	Ketamine	1.5-2	5-10	2-6	2-6	Up to 2	2-6
9	Telazol	0.5-1.5	2-10	2-8	4-10	1-4	2-10
10	Guaifenesin	50-100	30-90	—	30-90	50-100	30-90
	Thiopental	4-6	4-9		4-9	4-6	—
11	Guaifenesin	50-100	30-90	—	—	50-100	—
	Ketamine	1.2-2.2	1	—	1-2	0.6-1.1	0.6-1.1
12	Acepromazine	—	0.2	0.2	0.4	—	—
	Ketamine	—	10	10	2-7	—	—
13	Xylazine*	1	0.7-1	0.7-1.1	1-2	0.04	0.04
	Ketamine	2.2	10	10-11	6-8	2	2-7
14	Xylazine	1.0-1.1	0.4	0.7	0.7	0.05	0.09
	Telazol	1.0-2.2	7	2-7	2-7	1	1
15	Diazepam†	0.1	0.25	0.2	0.2	0.25-0.5	—
	Ketamine	1.5-2	5	5	4	5-10	—
16	Midazolam	—	—	0.4	—	—	—
	Ketamine	—	—	7.5	—	—	—
17	Midazolam	0.02	—	—	—	—	—
	Xylazine	1	—	—	—	—	—
	Propofol	3	—	—	—	—	—
18	Oxymorphone	—	—	—	0.08	—	—
	Xylazine	—	—	—	2	—	—
	Ketamine	—	—	—	2	—	—
19	Xylazine, guaifenesin, ketamine	(500 mL 5% guaifenesin + 500 mg ketamine + 30-50 mg xylazine [ruminants 1-2 mL/kg]; 500 mL 5% guaifenesin + 500 mg ketamine + 500 mg xylazine [horses, pigs]); approximately 3-5 mL/min until effective					

*Dexmedetomidine (small animals) or Detomidine (horses; farm animals), 2 to 10 μg/kg IV, can be administered to replace xylazine.
†Midazolam, 0.2 to 0.6 mg/kg IV, can be administered to replace diazepam.

II. Nonproprietary drug names

Drug	Appropriate Duration of Action
Phenobarbital sodium	Long
Pentobarbital sodium	Short
Thiopental sodium	Ultrashort
Methohexital	Ultrashort

III. General anesthetic actions

A. Effects on the CNS

1. CNS depression ranging from drowsiness and mild sedation to coma results from interaction with gamma aminobutyric acid A (GABA A) receptors which inhibit CNS activity
2. Response to barbiturate anesthesia
   a. Pentobarbital and ultrashort-acting barbiturates (thiopental, methohexital) decrease cerebral blood flow (CBF), cerebral metabolic rate of oxygen ($CMRO_2$), and neuronal activity of the brain (e.g., dogs); the CBF/$CMRO_2$ ratio is unchanged or increased; minimal changes in CSF pressure occur if ventilation ($PaCO_2$) is normal
   b. Anesthetic concentrations of barbiturates decrease cardiac contractile force and vasomotor tone resulting in depression of arterial blood pressure (BP) and a decrease in intracranial pressure
   c. Ultrashort- and short-acting barbiturates are used to produce general anesthesia or to induce an animal to surgical anesthesia
   d. Barbiturates are poor analgesics at subhypnotic doses
3. Anticonvulsant effects
   a. Long- or intermediate-acting barbiturates are used for control of convulsions
   b. Short-acting barbiturates (pentobarbital) can be used for acute control of seizures. Infusions of pentobarbital are cumulative.

Useful Facts ▪ Barbiturates

- Short- or ultrashort-acting barbiturates are used for anesthesia
- Long- or intermediate-acting barbiturates are used as anticonvulsants (phenobarbital)
- Decrease CBF and $CMRO_2$; useful for CNS surgery

B. Organ system effects and responses
   1. Respiratory system
      a. Barbiturates are respiratory depressants
         (1) Respiratory centers in the medulla and areas of the brain responsible for the characteristic rhythmic pattern of respiratory movement (apneustic and pneumotaxic centers) are depressed
         (2) Barbiturates depress the ventilatory response (minute ventilation) to increases in $PaCO_2$
         (3) The degree of respiratory depression is related to the dose and rate of administration
      b. Coughing, sneezing, hiccoughing, and laryngospasm occur during induction; these effects are exaggerated by excessive salivary secretion and are minimized by preanesthetic medication (atropine, glycopyrrolate)
         (1) Laryngospasm is an infrequent complication of barbiturate anesthesia in cats
      c. A short period of apnea frequently occurs after IV bolus administration of barbiturates
         (1) If apnea occurs, attention should be directed toward establishing an airway and ventilating the animal
   2. Cardiovascular system
      a. Barbiturates produce significant cardiovascular depression. Cardiac contractile force and vasomotor tone are decreased. Induction to anesthesia is generally associated with a transient fall in BP, particularly if a bolus or large dose of drug is administered.
      b. Cardiac arrhythmias may occur (Fig. 8-1)



FIG. 8-1. Canine electrocardiogram showing unifocal (monomorphic) ventricular tachycardia (*top trace*). Conversion to sinus tachycardia after lidocaine IV (*bottom trace*).

(1) Thiobarbiturates (thiopental) sensitize the heart to epinephrine and induce autonomic imbalance; arrhythmias, particularly ventricular extrasystoles (ventricular bigeminy, trigeminy) can occur after thiopental administration
(2) Thiobarbiturates increase both parasympathetic and sympathetic tone; this may lead to atrial or ventricular arrhythmias; rarely sinus bradycardia; first-, second-, or third-degree heart block and cardiac arrest occur

c. Barbiturates usually cause a transient drop in BP; small doses of a barbiturate may cause dramatic decreases in cardiac contractility, cardiac output, and arterial BP in sick, depressed, or debilitated animals
(1) Reduced doses should be administered very slowly to sick, debilitated, or depressed animals
(2) Concentrations of thiopental greater than 2.5% are toxic to tissues if inadvertently administered subcutaneously and may injure the capillary musculature, causing capillary dilation and thrombophlebitis; injection into an artery causes severe pain, vasoconstriction, and tissue necrosis
(3) Induction doses of thiobarbiturates occasionally cause an initial increase in BP and tachycardia in stressed or excited animals due to an increase in sympathetic tone. Note: pentobarbital produces an atropine-like effect.

3. Actions on the gastrointestinal (GI) system
a. Depress intestinal motility
b. Kidney and liver
(1) No direct effect on the kidney has been observed, unless a decrease in renal blood flow occurs; systemic hypotension may cause a decrease or cessation in urine production
(2) A single administration of thiopental at therapeutic doses has no effect on liver function; large or repetitive doses of barbiturates do not interfere with liver function providing hemodynamics (BP and blood flow) are maintained

4. Effects on the uterus and fetus
a. Pentobarbital is contraindicated in near-term animals because of fetal respiratory depression

b. Barbiturates readily diffuse across the placenta into the fetal circulation; thiopental reaches mixed fetal cord blood within 45 seconds
c. Doses of barbiturates that do not produce anesthesia in the mother can completely inhibit fetal respiratory movements

IV. Absorption, elimination, and excretion

A. Absorption

1. IV administration
   a. Always be prepared to support respiration and circulation
   b. Short-acting barbiturates (pentobarbital) require approximately 5 to 10 minutes to produce maximal CNS effects
   c. Ultrashort-acting barbiturates (thiopental, methohexital) generally produce maximal effect within 30 seconds
2. Barbiturates are absorbed from the GI tract after oral administration

B. Elimination

1. Redistribution: the CNS effects of ultrashort-acting barbiturates (thiopental) end because of redistribution to lean body tissues (muscle) (Fig. 8-2)
   a. Emergence from sleep depends on a shift of the drug from the brain to lean body tissues
   b. Drug concentrations in muscle and skin peak approximately 15 to 30 minutes after thiobarbiturate injection
   c. Drug concentrations in fat peak after several hours
   d. Repeated doses have a cumulative effect
   e. Extremely thin, heavily muscled animals (e.g., greyhounds, whippets) demonstrate prolonged recoveries (3 to 5 hours) from thiopental
   f. Obesity may delay terminal drug elimination because of the high lipid solubility of barbiturates
   g. "Acute tolerance" (minimal effect with a usual dose) is rarely observed after the administration of thiobarbiturates; the mechanism is unknown but may be related to the animal's level of excitement and the distribution of cardiac output; if this occurs, alternative anesthetic techniques should be considered

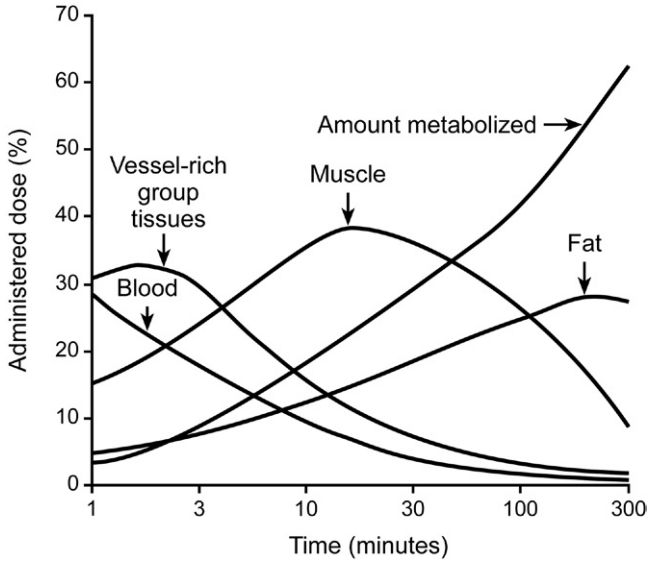


FIG. 8-2. Distribution and *redistribution* of thiopental to tissues. Note that the accumulation of drug in muscle corresponds to the approximate duration of thiopental anesthetic effect. Similar redistribution occurs with propofol.

2. Barbiturates are terminally eliminated by oxidative activity of hepatic enzymes and by renal excretion
3. The amount of active (nonionized, nonprotein-bound) drug is increased by acidosis and low plasma protein concentrations; alkalinization hastens drug elimination. This is effective for pentobarbital.

C. Excretion
   1. Hepatic metabolism
      a. Barbiturates are metabolized by both hepatic and extrahepatic mechanisms; metabolites are eliminated by the kidneys and appear in the urine
      b. Liver disease may prolong the duration of drug action; avoid using short-acting barbiturates (pentobarbital) in the presence of liver disease
      c. Hypothermia and depressed cardiovascular function may prolong hepatic metabolism of barbiturates
      d. Hepatic metabolism of thiobarbiturates is delayed in greyhounds and potentially other sight hounds, prolonging their duration of action

V. Dose and administration of specific barbiturate drugs
- A. Pentobarbital sodium
  1. IV anesthetic doses vary from 10 to 50 mg/kg of body weight, depending on quality of preanesthetic sedation
     a. Approximately half the anticipated dose should be injected relatively rapidly (approx. 10 to 15 seconds); the remainder should be administered in small increments until the desired effect is reached
  2. May be used in combination with other anesthetics (inhalants) to maintain surgical anesthesia
  3. Preanesthetic drugs decrease the dose of barbiturates required to produce anesthesia
  4. Atropine or glycopyrrolate decreases salivary secretions, the potential for laryngospasm, and vagal activity
  5. The anesthetic duration can be prolonged by administration of 50% glucose IV; this is referred to as the *glucose effect*
  6. Complete recovery occurs in 8 to 24 hours
  7. The minimum lethal dose in dogs is 50 mg/kg IV
  8. Overdose is treated by ventilation, drugs that increase cardiac output, fluid therapy, alkalinizing solutions (Na^+ HCO_3^-), and diuresis
  9. Oral administration is neither safe nor practical for dogs or cats
- B. Thiopental sodium
  1. Generally administered IV in small increments to produce anesthesia (3 to 12 mg/kg)
  2. Useful concentrations range from 1.25% to 10% solutions
     a. Solution should be discarded after being stored for 7 days in a refrigerator at 50° C to 60° C or 3 days at room temperature; precipitated solutions should not be used
     b. Concentrated solutions (>2%) can cause tissue damage and necrosis if accidentally administered perivascularly
     c. Tissue necrosis may be minimized by infiltrating the area with saline solution; pain can be minimized by injecting 2% lidocaine
  3. Dose for induction and intubation is 3 to 6 mg/kg; solutions of up to 10% are used in horses; repeated doses are cumulative and may result in prolonged recovery from anesthesia

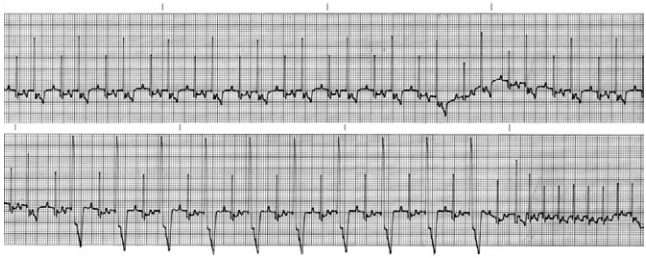


FIG. 8-3. Electrocardiogram showing ventricular bigeminy (every other QRS complex is abnormal) produced by the rapid administration of thiopental to a dog. Note conversion to sinus rhythm at the end of the bottom trace.

4. Dose should be based on lean body weight (body weight minus fat)
5. Anesthesia usually occurs in 20 to 60 seconds
6. Ventricular arrhythmias (ventricular extrasystoles, bigeminy, trigeminy) may occur after induction of anesthesia (Fig. 8-3)
7. Apnea is more common after rapid IV injection; breathing should be supported early in anesthesia
8. Recovery from a single bolus occurs in 10 to 30 minutes, but the animal may remain depressed for many hours depending on the dose; repeated doses are cumulative
   a. Single doses may result in prolonged recovery from anesthesia in sight hounds. Hepatic metabolism is slow and body fat is limited.
9. Overdose is best treated with oxygen, controlled ventilation, fluid administration, alkalinizing solutions, and diuretics

C. Methohexital
1. Similar to thiopental, except it is less cumulative (it is rapidly metabolized)
2. 6 to 10 mg/kg provides light anesthesia in small animals; 6 mg/kg in horses and adult cattle; 3 to 5 mg/ kg in calves
3. Solutions are stable at room temperature for at least 6 weeks
4. Recommended in sight hounds (e.g., greyhounds, whippets, borzois) because of its short duration of action
5. Duration is 5 to 10 minutes; less than thiobarbiturates
6. Respiratory depression and apnea are common
7. Induction and recovery may be accompanied by pronounced excitement, myoclonus, delirium, and

seizures; the potential for CNS effects can be minimized by benzodiazepines (diazepam 0.2 mg/kg IV); the recovery period may be associated with muscle tremors and struggling even with preanesthetic sedation in horses

8. Not routinely used in large animals

Doses ▪ Barbiturates

Agent	Animal	Dose	Duration
Pentobarbital sodium	Dogs	10-33 mg/kg	30 min
	Cats	25 mg/kg	
	Horses	Not recommended	
	Cattle	15-30 mg/kg	
	Pigs	10-30 mg/kg	
Thiopental sodium	Small animals	3-12 mg/kg	10-30 min
	Horses	5-8 mg/kg	
	Cattle	5-10 mg/kg	
	Calves	5-12 mg/kg	
	Pigs	5.5-11 mg/kg	
Methohexital	Small animals	6-10 mg/kg	5-10 min
	Horses	6 mg/kg (Not recommended)	
	Cattle	6 mg/kg (Not recommended)	
	Calves	3-5 mg/kg	

Cautions ▪ Barbiturates

- Respiratory depression; apnea
- Cardiovascular depression (transient hypotension)
  Tissue toxicity when greater than 2.5% IV is administered; intraarterial injection may cause severe pain, vasoconstriction, and tissue necrosis
- Minimal effects on liver or renal function at anesthetic doses
- Methohexital can cause excitement and myoclonus during induction and recovery from anesthesia

Nonbarbiturate Anesthetic Drugs

I. Etomidate

A. A rapid-acting, ultrashort, nonbarbiturate, imidazole compound that is noncumulative

B. General anesthetic actions

1. Produces hypnosis (sleep) by binding to GABA A receptors
2. The reticular-activating system is a primary site of action

3. Enhances monosynaptic reflex activity, which may result in myoclonal activity
4. Decreases CBF and $CMRO_2$; increases ratio of CBF to $CMRO_2$
5. Not a good analgesic at subhypnotic doses

C. Organ system effects
1. Respiratory system
   a. Apnea may occur after IV bolus injection
   b. Tidal volume and respiratory rate are minimally affected during anesthetic maintenance; respiratory rate may increase
2. Cardiovascular system
   a. Produces little change in heart rate, arterial BP, and cardiac output when administered slowly IV
   b. Cardiac contractility is mildly depressed
   c. Does not sensitize the myocardium to catecholamine-induced cardiac arrhythmias
   d. Does not produce histamine release
3. GI system
   a. Nausea and vomiting are occasionally observed during induction or after anesthesia in animals that have not been premedicated; nausea and vomiting are inhibited by proper preanesthetic medication
   b. GI motility is minimally affected
4. Endocrine system
   a. An antiglucocorticoid and antimineralocorticoid effect is produced; adrenocorticotropic hormone stimulation tests and glucose tolerance tests may be invalid
   b. Adrenocorticoid function is suppressed for 2 to 3 hours in dogs after a single IV administration of etomidate. Adrenocorticoid suppression is not considered to be clinically relevant in normal dogs and cats, particularly after single use.
5. Crosses the placenta, but effects are minimal because of the rapid clearance

D. Fate and elimination
1. Rapid recovery due to redistribution to the brain, heart, spleen, lungs, liver, and intestines
2. Anesthetic duration of action depends on drug redistribution and capacity; ester hydrolysis by the liver
3. Noncumulative

E. Other
   1. Produces adequate muscle relaxation during anesthesia; involuntary muscle movements and myoclonic reactions may occur during induction and recovery especially in animals that have not been premedicated
   2. Has not been associated with the development of malignant hyperthermia
   3. Pain may occur during injection
   4. Decreases intraocular pressure
   5. Can cause acute hemolysis; 4965 mOsmol/L in propylene glycol

F. Clinical uses
   1. Induction to general anesthesia
   2. Short-term (5 to 10 minutes) anesthesia in dogs and cats; should be administered in conjunction with muscle relaxants (e.g., diazepam), sedatives (e.g., dexmedetomidine), and analgesics (e.g., fentanyl) for best effect
   3. Generally not used in equine or food-producing animals (expensive)

G. Doses
   1. 0.5 to 3 mg/kg IV in dogs and cats
   2. The best results are obtained after sedating the animal with diazepam, dexmedetomidine, or acepromazine

Cautions ▪ Etomidate

- Regurgitation and vomiting
- Pain on IV injection
- May cause hemolysis
- Myoclonus
- Transient (>3 hr) adrenocortical suppression in dogs and cats

II. Propofol

A. A rapid-acting, ultrashort, nonbarbiturate; a relatively noncumulative IV anesthetic

B. General anesthetic actions
   1. Produces sedation-hypnosis similar to other hypnotics by binding to GABA A receptors and by acting as a sodium channel blocker
   2. Produces dose-dependent depression of the cerebral cortex and CNS polysynaptic reflexes; may enhance the effects of nondepolarizing neuromuscular blocking drugs

3. Produces minimal analgesia at subhypnotic doses
4. Anesthetic doses decrease CBF and $CMRO_2$; the CBF/$CMRO_2$ ratio is unchanged or minimally increased
5. Produces anticonvulsant and antiemetic effects

Useful Facts ▪ Propofol

- Rapid onset and recovery
- Relatively noncumulative
- Excellent for induction to anesthesia and short-term anesthetic procedures (e.g., endoscopy)
- Minimal hangover (drug carry-over effects)

C. Chemistry
   1. An alkylphenol that is poorly soluble in water
   2. Solubilized in a lecithin-containing emulsion (10% soybean oil and 1.2% egg lecithin) called Intralipid
      a. Various water soluble propofol analogues have been developed to avoid issues associated with Intralipid, particularly increased potential for infection
   3. Nanodroplet formulations and specialized solubilizing diluents (2-hydroxypropyl β-cyclodextrin [HPCD]) are being investigated for clinical use to limit storage and bacterial growth issues with current (Intralipid) formulations

D. Organ system effects
   1. Respiratory system
      a. Similar to thiopental
      b. Dose-dependent respiratory depression and initial periods of apnea
      c. Always be prepared to support ventilation
   2. Cardiovascular system
      a. Produces little change in heart rate
      b. Dose-dependent decreases in arterial BP transiently caused by decreases in cardiac output and systemic vascular resistance
      c. Minimal but dose-dependent negative inotropic effect at anesthetic doses
      d. Sensitizes the heart to catecholamine-induced arrhythmias to a lesser extent than thiobarbiturates; effect is not clinically relevant in otherwise healthy animals

3. Other organ systems: liver, kidney, and GI system effects are the result of changes in arterial BP and organ blood flow
4. Crosses the placenta and can induce dose-dependent fetal depression

E. Fate and elimination
1. Termination of anesthetic effects and short duration of action are due to the drug's large volume of distribution, which allows redistribution from the brain to muscle and fat
2. Relatively rapidly redistributed and biotransformed by the liver
3. Rapid clearing from the body by hepatic and extrahepatic metabolism compared with thiobarbiturates
4. Relatively noncumulative

F. Other
1. Produces good to excellent muscle relaxation
2. May elicit pain on induction to anesthesia
3. Rapid recovery; little or no hangover effect
4. Capable of supporting microbial growth and endotoxin production
5. May induce oxidative injury to feline red blood cells resulting in hemolysis (Heinz body anemia) particularly when administered on consecutive days to cats (comparative low glucuronide conjugation capabilities)

G. Clinical uses
1. Induction to general anesthesia
   a. Safe and effective in sight hounds (e.g., greyhounds)
2. Maintenance of general anesthesia when combined in conjunction with opioid analgesics or other sedative-analgesic drugs
3. Can be used for cesarean section surgery with generally good results

Cautions ▪ Propofol

- Dose- and administration rate–dependent respiratory depression
- Cardiovascular depression; hypotension and occasional bradycardia
- Intralipid supports microbial growth and may support infection
- Potential for hemolysis and Heinz body anemia (cats)

H. Doses
1. 2 to 8 mg/kg IV in dogs and cats for induction
2. Premedication allows for a reduction in dose
3. 0.2 to 0.6 mg/kg/min IV infusion in dogs and cats for anesthesia maintenance; usually used with diazepam for added muscle relaxation, oxymorphone or fentanyl for analgesia, and dexmedetomidine or acepromazine for sedation

III. Alphaxalone (Alfaxan CD-RTU)

A. A rapid, short-acting, nonbarbiturate steroid anesthetic
1. Alphaxalone is complexed with HPCD (similar to propofol, see above) to improve water solubility
2. HPCDs form stabile aqueous complexes
3. Importantly, HPCD is not associated with histamine release and does not support bacterial growth

B. General anesthetic actions
1. Produces sedation-hypnosis similar to other hypnotics by binding to GABA A receptors
2. Produces dose-dependent depression of the cerebral cortex and CNS polysynaptic reflexes
3. Produces minimal analgesia at subhypnotic doses
4. Anesthetic doses decrease CBF and $CMRO_2$
5. Pharmacologic and pharmacokinetic effects are dose dependent
   a. Drug accumulation is not important when administered in clinically relevant dosages

Useful Facts ▪ Alphaxalone

- Rapid and uneventful onset and recovery from anesthesia in dogs and cats: requires preanesthetic sedation especially in horses, ruminants, and camelids
- Relatively noncumulative
- Excellent for induction to anesthesia and short-term medical or surgical procedures
- Minimal hangover (drug carry-over effects)

C. Chemistry
1. A steroidal compound that is poorly soluble in water
2. Previous formulations were solubilized in polyethoxylated castor oil (Cremophor-EL) causing histamine release
   a. Current formulations are solubilized in HPCD, thereby improving water solubility and safety

D. Organ system effects
   1. Respiratory system
      a. Dose-dependent respiratory depression and initial periods of apnea
   2. Cardiovascular system
      a. Minimal cardiovascular depression when administered at clinically relevant doses
      b. Increases in heart rate and, occasionally, sinus tachycardia
      c. Dose-dependent decreases in arterial BP vasodilatation
      d. Minimal but dose-dependent negative inotropic effect at anesthetic doses
   3. Other organ systems: liver, kidney, and GI system effects are the result of changes in arterial BP and organ blood flow
   4. Crosses the placenta and can induce fetal depression, which is dose-dependent

E. Fate and elimination
   1. Rapidly metabolized in the liver; some metabolites are eliminated in the urine
   2. Nonlinear pharmacokinetics in cats suggesting that drug effects and persistence of effects are not predictable at different doses
   3. Rapidly cleared from the plasma and relatively noncumulative at clinical doses

F. Other
   1. Produces good to excellent muscle relaxation
   2. Uneventful but dose-dependent duration of recovery

G. Clinical uses
   1. Induction to general anesthesia
      a. Safe and effective in sight hounds (e.g., greyhounds)
   2. Maintenance of general anesthesia when combined in conjunction with opioid analgesics or other sedative-analgesic drugs

Cautions ▪ Alphaxalone

- Dose- and rate of administration rate–dependent respiratory depression
- Hypotension
- Animals may become hyperresponsive to sound during recovery

H. Doses
   1. Wide margin of safety and can be administered IM, IV as a bolus, or by IV infusion
      a. Alphaxalone not irritating to tissues
   2. IV dosages range from 2 to 5 mg/kg for induction to anesthesia in dogs and cats; repeated doses (2 mg/kg IV) can be used to maintain anesthesia
      a. 0.07 to 0.1 mg/kg/min (4 to 7 mg/kg/hr) IV infusion in dogs and cats for maintenance
   3. IM dosages range from 12 to 15 mg/kg
   4. Compatible with diazepam or midazolam for added muscle relaxation, oxymorphone or fentanyl for analgesia, and acepromazine or dexmedetomidine for sedation

IV. Chloral hydrate

A. Chloral hydrate, a sedative hypnotic, is no longer sold as an anesthetic but can be purchased as crystals and dissolved in water for IV or oral administration to produce sedation or hypnosis, or for euthanasia. Most frequently used in horses and farm animals.

B. General anesthetic actions
   1. Chloral hydrate is metabolized to trichloroethanol, producing an effect similar to alcohol (ethanol) intoxication and resulting in depression of the cerebral cortex and producing hyporeflexia. It is a poor analgesic at subanesthetic doses.
   2. Subanesthetic doses depress motor and sensory nerves and produce anxiolysis, which is mild sedation. Anesthetic doses approach the minimum lethal dose.
   3. Anesthetic doses produce deep sleep lasting for several hours; recovery is prolonged (6 to 24 hours)

C. Chemistry
   1. Physical properties: colorless, translucent crystals that volatilize when exposed to air
   2. Chemical properties
      a. Readily soluble in both water and oil
      b. Bitter, caustic taste; irritating to the skin and mucous membranes

D. Organ system effects
   1. Depresses respiratory rate and tidal volume
   2. Myocardial contractility is depressed; vagal tone increases, causing bradycardia

3. GI secretions and motility are increased, diarrhea may occur after anesthesia
4. Chloral hydrate readily crosses the placenta

E. Clinical uses
1. Administered IV, orally, and rectally. Not IM or IP. Very irritating if given perivascularly.
2. Not administered for small-animal anesthesia
3. Occasionally administered as a sedative in large animals; the dose for anesthesia is variable (up to 200 mg/kg IV)
4. Choral hydrate crystals can be obtained from chemical companies (Sigma-Aldrich Co., LLC)

F. Dose
1. Sedation: 20-60 mg/kg IV
2. Anesthesia: up to 200 mg/kg IV

V. Guaifenesin (glyceryl guaiacolate ether)

A. Chemistry
1. Physical properties: a white, finely granular powder that is soluble in water
2. Chemical properties
   a. A decongestant and antitussive and a centrally acting muscle relaxant
   b. Similar to mephenesin chemically; mephenesin is an aromatic glycerol ether

B. General anesthetic actions
1. Blocks impulse transmission at internuncial (inter) neurons of the spinal cord and brainstem; guaifenesin is a centrally acting muscle relaxant
2. Produces minimal sedation and analgesia
3. Produces skeletal muscle relaxation but minimal effects on respiration at relaxant doses
4. Relaxes laryngeal and pharyngeal muscles, facilitating intubation of the trachea
5. Compatible with preanesthetic and anesthetic agents
6. Produces excitement-free induction and recovery from anesthesia
7. Produces paradoxical increases in muscle rigidity when large doses are administered

C. Organ system effects
1. Respiratory system
   a. Little, if any, respiratory depression
   b. Respiratory rate may increase initially; tidal volume decreases

Useful Facts ▪ Guaifenesin

- Poor anesthetic when administered alone
- Good to excellent skeletal muscle relaxation
- Relaxes laryngeal and pharyngeal muscles, facilitating intubation
- Good recovery

   c. Excessive doses produce an apneustic (breath holding) pattern of breathing
   d. Oxygenation is reduced when recumbency is produced
2. Cardiovascular system
   a. Initial mild decrease in BP, which returns to normal
   b. Myocardial contractile force and heart rate are relatively unchanged
3. GI system: increases GI motility
4. Uterus and fetus: guaifenesin crosses the placental barrier but does not produce significant respiratory depression in the fetus

D. Absorption, fate, and excretion: excreted in the urine after conjugation in the liver to a glucuronide

E. Clinical uses
1. Administered to horses and farm animals to produce muscle relaxation
2. Used in combination (thiobarbiturates, ketamine) for short anesthetic procedures up to 60 minutes
3. Dissolved in water or 5% dextrose as a 5% to 10% solution
   a. High concentrations (>6%) may cause hemolysis and hemoglobinuria in cattle; solutions greater than 15% cause hives and hemolysis in horses
4. Often made by mixing 50 g guaifenesin with 50 g dextrose and 1 L warm sterile water (5% solution)
5. Compatible with other IV and inhalant anesthetic drugs

Cautions ▪ Guaifenesin

- High concentration (>6%) may cause hemolysis and hemoglobinuria in cattle; greater than 15% causes hives and hemolysis in horses and cattle

F. Dose
   1. The dose varies from 50 to 100 mg/kg IV
   2. Guaifenesin (1 L) is frequently administered until effective with:
      a. 2 g thiopental
      b. 2.5 g pentobarbital
      c. Ketamine (500 mg) and xylazine (250 mg) are mixed with 500 mL of 5% guaifenesin and administered at a rate of 2 mL/kg/hr to extend intravenous anesthesia in horses. For cattle, only 20 to 40 mg of xylazine should be added.
   3. The margin of safety (guaifenesin alone) is approximately three times the anesthetic doses (dose producing recumbency) dose (approximately 300 mg/kg IV)
   4. Excessive doses usually indicated by muscle rigidity and an apneustic pattern of breathing

Dissociogenic Anesthetic Drugs

"Dissociative" anesthetics are arylcyclohexylamines and include ketamine, tiletamine, and phencyclidine (not discussed)

I. Anesthesia is characterized by profound neurogenic motor immobility (catatonia), muscle rigidity and a statue-like posture (catalepsy), and dose-dependent analgesia. Animals may not initially appear to be anesthetized, with frequent swallowing and ocular movement.
   A. Oral, ocular, and swallowing reflexes remain intact, and muscle tone can be increased, particularly if drugs with muscle relaxant activity are not co-administered
      1. Muscle rigidity is minimized by the previous administration of tranquilizers, sedatives, benzodiazepines (diazepam, midazolam)
   B. Large doses may produce seizures, which can be controlled with small doses of pentobarbital, thiopental, propofol, diazepam, or midazolam
   C. Ketamine and other dissociative anesthetics are noncompetitive NMDA receptor antagonists

II. Hallucinations, confusion, agitation, and fear have occurred in humans and seem to occur in some animals during or following recovery from anesthesia when large doses have been administered

III. Specific drugs

A. Ketamine is the most commonly administered dissociative anesthetic in veterinary practice
   1. Ketamine is generally administered in combination with sedatives and muscle relaxants (α_2-agonists; benzodiazepines) to induce anesthesia and produce immobilization for minor surgical procedures
   2. Ketamine is also administered by infusion to enhance analgesia to reduce inhalant or injectable anesthetic requirements
   3. Palpebral, corneal, and swallowing reflexes persist; nystagmus is common

B. Telazol, a 1:1 drug combination of zolazepam (a benzodiazepine) and tiletamine (50 mg/mL of each); tiletamine is pharmacologically classified as an NMDA receptor antagonist and can be administered to all species; Telazol is supplied as a soluble powder for reconstitution with 5 mL of saline
   1. The addition of 5 mL diluent produces a solution containing 50 mg tiletamine base, 50 mg zolazepam base and 57.7 mg mannitol/mL. This solution pH ranges from 2 to 3.5 and is recommended for IM injection.
   2. Telazol is very useful in aggressive dogs or cats and exotic animals and the dilution of Telazol powder with 1 mL of xylazine (100 mg/mL) or dexmedetomidine (0.5 mg/mL) and 4 mL of ketamine (100 mg/mL) to produce anesthetics called TKX or TKD, respectively, is used to produce immobilization and short term anesthesia

IV. Salivation and lacrimation are common and may become copious. Swallowing may make it difficult to place an endotracheal tube

V. Tremors, rotary nystagmus (oculogyric activity), tonic spasticity, and seizures occur when excessive doses are administered.

VI. Muscle relaxation is poor; all dissociative anesthetics are best administered with drugs that produce muscle relaxation and added sedation (e.g., benzodiazepines; α_2-agonists)

VII. Some animals develop hyperreflexia and hyperresponsiveness to physical stimulation and sound. Ataxia following recovery from anesthesia may persist for hours and "emergence delirium" may develop.

VIII. Analgesia is dose dependent and prominent in superficial pain models; visceral pain is not abolished

IX. Systemic effects and responses

A. CNS
   1. Dissociative anesthesia is characterized by catatonia and catalepsy, analgesia, and retention of ocular and laryngeal responses to physical stimulation
   2. Ketamine increases CBF and causes no change or an increase in $CMRO_2$; the $CBF/CMRO_2$ ratio increases; arterial BP and intracranial pressure increase; cerebral perfusion pressure decreases

B. Respiratory system
   1. Dissociative anesthesia is characterized by breath holding (apneustic pattern of breathing); respiratory rate may be increased; arterial PO_2 generally falls after IV administration
   2. Possible increases in PCO_2 and decreases in arterial pH are caused by the irregular pattern of breathing

C. Cardiovascular system
   1. Increased heart rate
   2. Increased BP
   3. Increases in heart rate and myocardial oxygen requirements and decreases in cardiac contractility may induce pulmonary edema or acute heart failure in animals with preexisting cardiac disease
   4. Ketamine and other dissociative anesthetics minimally sensitize the heart to catecholamine-induced arrhythmias

D. Kidney and liver
   1. Ketamine is metabolized by the liver and excreted by the kidneys
   2. Ketamine undergoes extensive hepatic metabolism, primarily via N-demethylation to norketamine, an active metabolite. Ketamine enantiomers are administered individually, or together as a racemic mixture; each differs in its hepatic clearance and duration of anesthetic effect. S(+) ketamine exhibits a greater clearance and faster anesthetic recovery compared with the racemate and a greater clearance compared to R(-) ketamine.
   3. Ketamine should be used with caution in animals with hepatic or renal disease; ketamine can be used in cats with urethral obstruction, provided that renal disease is absent or not severe and the obstruction is eliminated

Useful Facts ▪ Ketamine

- Immobilization
- Somatic analgesia
- Wide therapeutic index (safe) compared to hypnotic anesthetics (thiopental, propofol)

XII. Dose

A. Ketamine

1. Extremely versatile and may be administered IV, IM, SQ, orally (buccally), rectally, and nasally with variable results. Minimal tissue irritation but painful given IM.
2. IV dosages range from 1 to 5 mg/kg but may use 10 mg/kg or larger in nondomesticated or exotic species
   a. Infusion dosages range from 10 to 50 μg/kg/min to provide analgesia and reduce inhalant or injectable anesthetic requirements
3. IM dosages generally range from 5 to 20 mg/kg but may be larger in nondomesticated or exotic species
4. SQ administration produces highly variable results

B. Telazol

1. Dogs, cats, cattle, sheep, goats: 2 to 5 mg/kg IV; 1 to 8 mg/kg IM
2. Horses
   a. Xylazine 1 mg/kg followed by 1 to 1.5 mg/kg Telazol, IV
   b. Telazol powder can be solubilized using detomidine (1 mL) and ketamine (4 mL of 100 mg/mL). The resulting solution is administered to achieve sedation in horses (xylazine, 0.6 mg/kg, IV) at a dose of 0.007 mL/kg, IV (1 mL/150 kg). Duration: 30 minutes.
3. Pigs: 500 mg of Telazol powder with 2.5 mL of xylazine (100 mg/mL) and 2.5 mL of ketamine (100 mg/mL); administer 1 to 2 mL/50 kg IM

Cautions ▪ Ketamine

- Inadequate anesthesia
- Poor muscle relaxation
- Tremor
- Tachycardia and respiratory depression
- Excitement during recovery

Inhalant Anesthesia and Inhalant Anesthetics

9

"O sleep! O gentle sleep! Nature's soft nurse, how have I frightened thee, That thou no more will weigh my eyelids down and steep my senses in forgetfulness?"
WILLIAM SHAKESPEARE

OVERVIEW

Inhalant anesthetic drugs (inhalants) act at the brain and spinal cord to produce general anesthesia. They are suitable for use in all species including reptiles, birds, fish, and zoo animals. Their safe use requires knowledge of their pharmacologic effects and physical and chemical properties. Anesthetic doses produce unconsciousness (hypnosis), immobilization (muscle relaxation, hyporeflexia), and analgesia. Inhalant anesthetics provide optimal control of anesthesia, rapid induction and recovery from anesthesia, and have minimal carryover ("hangover") effects. Adjuncts to anesthesia (tranquilizers, analgesics) are frequently used in conjunction with inhalants to augment the quality of anesthesia and reduce the amount of inhalant anesthetic required to maintain anesthesia, thereby decreasing cardiorespiratory depression.

General Considerations

I. Inhalant anesthetics are vapors or gases that are inhaled directly into the respiratory system
II. To produce anesthesia, inhalant anesthetics must be absorbed from the alveoli into the bloodstream and carried by the blood to the central nervous system (CNS)
III. Inhalant anesthetics are primarily eliminated by the lungs
    A. Some metabolism occurs in the liver
IV. The uptake and elimination of inhalant anesthetic drugs are relatively rapid, thus the depth of anesthesia can be controlled effectively, but constant monitoring is required
V. The classical stages and planes of anesthesia (Fig. 9-1) were developed by Guedel for ether anesthesia and continue to be loosely applied to most inhalant anesthetics

Anesthetic level	Reaction to surgical stimulation	Muscle tone (jaw)	Palpebral reflex	Eye and pupil position	Ventilatory rate	Heart rate
Stage I	+		+		N	N
Stage II	+		+		↑	↑
Stage III Light	±		+		N↑	N↑
Medium	−		−		N↓ Intercostal lag	N↓
Deep	−		−		Abdominal slow shallow	↓↓
Stage IV	Ventilatory and cardiac arrest					

FIG. 9-1. Increasing "depth" of anesthesia produces characteristic changes in ocular, motor reflex, respiratory, and cardiovascular responses. These effects were originally described for ether by Guedel as the stages and planes of anesthesia. Although not perfect, they are useful for determining inhalant anesthetic (isoflurane, sevoflurane) effects. Moderate (medium) levels of inhalant anesthesia (stage III) are ideal for most invasive surgical procedures. Minimal (light) levels of stage III anesthesia can be administered for minor surgical procedures (biopsy, laceration repair) if analgesia is supplemented by local anesthetics or opioids.

A. Stage I: analgesia (from the beginning of induction to the loss of consciousness)
   1. Disorientation, with normal reflexes or hyperreflexia, is the most common feature
   2. Anxiety, increased heart rate, and rapid respirations may occur
   3. Excessive salivation may occur
B. Stage II: delirium or excitement, which represents the period of early loss of consciousness
   1. Potential hazards of stage II include struggling, physical injury, and increased sympathetic tone
   2. Voluntary centers in the brain become depressed; the patient becomes unaware of its surroundings
   3. During light anesthesia, the animal may react to stimuli (e.g., sound) with exaggerated struggling
   4. Respirations are generally irregular in depth and rate, and breath holding may occur
   5. The eyelids are widely open, and the pupils are dilated because of sympathetic stimulation

6. Reflex vomiting may occur unless food has been withheld; defecation and urination may occur
7. The duration of stage II can be decreased or eliminated by preanesthetic medication

C. Stage III
1. Plane I: marked by more regular respiration
   a. Carbon dioxide (CO_2) retention during the preceding stages may double tidal volume for the first few minutes
   b. Preanesthetic medication directly affects the rate and volume of respiration
   c. Responses to pain, although depressed, are still present
   d. Cardiovascular function is only minimally affected
2. Plane II: respiratory rate may be increased or decreased and respiratory volume (tidal volume) is decreased; cardiovascular function is mildly depressed
3. Plane III: loss of intercostal muscle activity
   a. Respiratory depression is significant
   b. Cardiovascular function is noticeably depressed
4. Plane IV: complete paralysis of muscles needed for breathing
   a. Cessation of all respiratory effort and dilation of the pupils
   b. Cardiovascular function is generally impaired, resulting in vasodilation leading to hypotension

D. Stage IV: respiratory arrest followed by circulatory collapse; death ensues within 1 to 5 minutes

Desirable Properties of Inhalant Anesthetic Drugs

I. Nonirritating and free from disagreeable odors
II. Easily controlled, producing rapid induction and recovery from anesthesia
III. Muscular relaxation; hyporeflexia
IV. Analgesia
V. Minimal side effects
VI. Nontoxic to the animal or the environment
VII. Not flammable or explosive (stable during storage)
VIII. Compatible with other drugs

Factors Controlling the Brain Tension of Inhalant Anesthetic Drugs

I. Physical and chemical properties of the drug (See Table 9-1)
A. Vapor pressure of the inhalant determines its volatility

TABLE 9-1 Boiling Points, Vapor Pressures, and Vaporization of Inhalant Anesthetic Drugs

Drug	Boiling Point (°C)	Vapor pressure at 20° C (mm Hg)	Maximum Concentration of Vapor (%) Delivered by Saturation Vaporizer at 20° C	*Useful Ranges of Concentration (agent used alone)*	
				Induction (%)	Maintenance (%)
VOLATILE ANESTHETIC DRUGS					
Desflurane	23.5	664	87.4	8-15	5-9
Sevoflurane	59	160	22	4-5	2.0-3.5
Isoflurane	48	252	33	2-6	1-3
Halothane	50	243	32	1-4	0.5-2.0
ANESTHETIC GAS					
Nitrous oxide*	-89	39,500 (50 atm)			

*Nitrous oxide is a gas at room temperature.

1. Volatility determines the design of the vaporizer used to deliver clinically relevant concentrations of inhalants (see Chapter 12)

B. Boiling points (other than for nitrous oxide [N_2O] and desflurane) are higher than room temperature (70° F or 27° C)
   1. N_2O is a gas at room temperatures. Its delivery is controlled using a flow meter
   2. Desflurane is delivered using an electrically heated vaporizer to deliver consistent concentrations

II. Anesthetic system

A. The concentration of inhalant delivered to the animal is determined by the type of vaporizer, the vaporizer setting, the fresh gas flow rate, and the type of anesthetic circuit (Chapter 12)

B. Frequent inspection and maintenance of inhalant anesthetic equipment is necessary to prevent malfunctions such as leaks and sticky one-way valves

III. Ventilation and uptake: The partial pressure of inhalant anesthetic in the brain and spinal cord depends on the alveolar

partial pressure; the alveolar partial pressure of an inhalant anesthetic is the result of the inspired concentration, the alveolar ventilation, and uptake from the lungs. Rapidity of uptake of inhalants is determined by their blood-gas partition coefficients, the cardiac output or lung blood flow, and the alveolar-to-venous partial pressure difference.

A. Inspired concentration
   1. Concentration effect: the greater the inspired concentration (vaporizer setting), the more rapid the rate of rise of the alveolar concentration
   2. Second-gas effect
      a. A 50% to 70% inspired concentration of N_2O initially augments the inflow and rate of uptake of a second gas (sevoflurane, isoflurane) in the inspired mixture

B. Alveolar ventilation
   1. Generally, the greater the ventilation (minute volume), the more rapid the approach of the alveolar gas concentration of any inhalant to its inspired gas concentration, but excessive hyperventilation may slow induction by reducing cerebral blood flow
   2. The rate of rise of the inhalant concentration in the alveoli may be delayed in the presence of large lung volumes because of the increased functional residual capacity (volume of gas in the lungs at the end of expiration)
   3. Factors affecting ventilation
      a. Respiratory rate
      b. Tidal volume
      c. Increased dead space (anatomic and physiologic) that develops during anesthesia results in decreased effective alveolar ventilation; tidal volume (V_T) = dead space volume (V_D) + alveolar ventilation (V_A): $V_T = V_D + V_A$
      d. Effective alveolar ventilation requires a patent airway
      e. Preanesthetic and induction drugs may cause respiratory depression, slowing the onset of action of inhalant anesthesia

C. Uptake of inhalant anesthetic from the lungs
   1. Solubility: describes how much of a substance can be dissolved in a gas, liquid, or solid (e.g., fat); the relative solubility of inhalants is usually expressed as a partition coefficient; how an inhalant is distributed between two

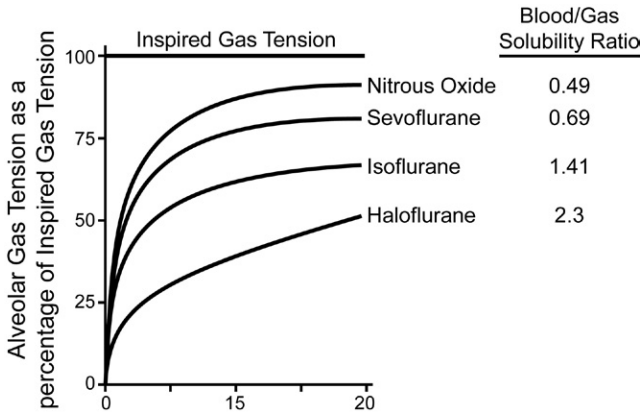


FIG. 9-2. The blood-gas solubility coefficient is a determinant of the rate of rise (rate of increase) of the alveolar inhalant concentration. The lower the blood gas solubility coefficient, the faster the increase in alveolar inhalant concentration and the faster induction and recovery from anesthesia (ex. sevoflurane faster than isoflurane).

phases (e.g., between blood and gas, between tissue and blood); Ostwald's partition coefficient expresses the solubility of an inhalant between blood and gas. An inhalant with a blood-gas partition coefficient of 2 has one volume in the alveoli per two volumes in the blood at equilibrium.

Blood-Gas Partitioning

Agent	Blood-Gas Partition Coefficient (Ostwald's coefficient)
Halothane	2.36
Isoflurane	1.41
Sevoflurane	0.69
Nitrous oxide	0.49
Desflurane	0.42

a. An inhalant's blood-gas partition coefficient and potency determine its rapidity of onset of effect
b. The greater the blood-gas partition coefficient, the greater the solubility of the inhalant in blood; the tension of the inhalant in arterial blood rises slowly for drugs that are highly soluble in blood (high blood-gas

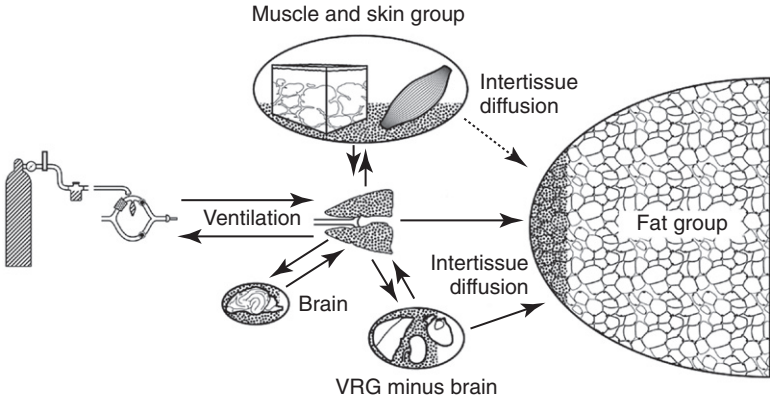


FIG. 9-3. Anesthetic delivery to tissues is dependent on blood flow. Lung, brain, heart, and major organs (liver, kidney) have a relatively high blood flow (vessel-rich group [VRG]) compared with muscle and fat and are more susceptible to anesthetic drug-related effects.

coefficient); onset of the clinical effect is contingent on the tension of the inhalant developed in the blood

c. Inhalants that are more soluble in blood have longer induction and recovery times because large amounts of inhalant must be taken into the blood before their tension (partial pressure) rises sufficiently to produce anesthesia; clinically, slow induction may be overcome by raising the inspired concentration of the inhalant anesthetic to values above those necessary to maintain anesthesia (anesthesia overpressure)

d. The lower the blood-gas partition coefficient, the less soluble the inhalant is in blood (only small quantities are carried in the blood); both alveolar concentration and tension will rise rapidly and blood inhalant anesthetic tension (partial pressure) increases rapidly (Fig. 9-2); less soluble inhalants: N_2O, isoflurane, and sevoflurane have comparatively short induction and short recovery times

2. Cardiac output: blood carries the inhalant anesthetic away from the lungs; the greater the cardiac output, the slower the rate of rise of alveolar concentration and the lower the partial pressure of the inhalant anesthetic in the lung and blood

a. Excited, stressed animals generally have an elevated cardiac output and a slower rate of induction because of the slower rate of rise of alveolar concentration and lower partial pressure of the inhalant anesthetic in the lungs; animals with a decreased cardiac output are induced to anesthesia very rapidly

3. Alveolar-venous anesthetic tension difference: during induction, tissues remove nearly all the inhalant brought to them because of the high tissue solubility of most inhalant anesthetics; venous blood returning to the lungs contains little inhalant; as time passes, increasing tissue saturation raises the venous blood concentration; therefore, less inhalant is taken up in the lungs; inhalant uptake is a continuous process towards a steady state (plateau) concentration
4. Other
   a. Right-to-left intracardiac or intrapulmonary shunts (e.g., Fallot's tetralogy) delay induction
   b. Left-to-right shunts can speed the rate of induction by increasing the rate of rise of the alveolar concentration and the partial pressure of the inhalant anesthetic in the lung; this occurs very rapidly if the cardiac output is low
   c. Pathologic changes in alveoli: if the alveolar membranes are affected by disease resulting in exudate, transudate, emphysema, or pulmonary fibrosis, diffusion may be impaired, and the uptake of the inhalant slowed

IV. Factors governing brain and tissue uptake of inhalants

A. The factors are the same as those determining uptake from the lungs
   1. Solubility (blood versus tissue)
   2. Tissue blood flow
   3. Arterial blood to tissue inhalant tension difference
B. The uptake by tissue is dependent on anesthetic tension in the blood, blood flow, and tissue capillary density
   1. Tissues can be categorized into four groups according to blood supply (Fig. 9-3)
      a. Vessel-rich group (VRG): 75% of cardiac output (e.g., brain, heart, intestines, liver, kidneys, spleen)
      b. Vessel-moderate group, or muscle group (MG): 15% to 20% of cardiac output (e.g., muscle, skin)

c. Fat group (FG): 5% of cardiac output (e.g., adipose tissue)
d. Vessel-poor group: 1% to 2% of cardiac output (e.g., bone, tendons, cartilage)

Blood Flow Groups

Group	Examples	Principal points
VRG: vessel-rich group	Brain, heart, liver	Equilibration of an inhalant anesthetic drug is complete in 5-20 minutes
MG: vessel-moderate group/muscle group	Muscle, skin	Equilibration of an inhalant anesthetic drug is complete in 1.5-4 hours
FG: neutral fat group	Adipose tissue	May affect recovery time after prolonged anesthesia

C. Tissue-blood partition coefficients vary less than blood-gas coefficients (except for fat)
   1. Lowest is approximately 1 (N_2O in lung tissue)
   2. Highest is approximately 4 (halothane in muscle tissue)

D. Important considerations
   1. Equilibration of an inhalant in the VRG is generally completed in 5 to 20 minutes; this is approximately how long it will take for anesthesia to become deep enough to do surgery, providing the anesthetic concentration (vaporizer setting) is appropriate
   2. Equilibration in the MG may take 1.5 to 4 hours
   3. Because of the higher blood flow, arterial-tissue partial pressure differences (and therefore uptake) decreases far more rapidly in VRG than in MG
      a. Solubility of an inhalant in VRG and MG may affect recovery time
   4. The FG occupies 10% to 30% body mass but receives only about 5% of the cardiac output
      a. FG tissue has a higher tissue solubility for inhalants than most other tissues and thus has a greater and more prolonged capacity to absorb them
      b. FG has little effect on induction of anesthesia because of its low blood flow
      c. FG may affect recovery time after prolonged anesthesia (3 hours or longer) because of the prolonged time it takes for the anesthetic to be eliminated from fat

Fat-Blood Partitioning	
Inhalant	**Fat-Blood Partition Coefficient**
Nitrous oxide	2.3
Desflurane	27.2
Isoflurane	48
Halothane	65
Sevoflurane	65

5. Vessel-poor group tissues have very little effect on the rate of induction and recovery from anesthesia
6. Rubber solubility: inhalants are freely absorbed into rubber components of anesthetic systems (if present); during recovery, inhalants equilibrate back into the anesthetic circuitry
   a. Contemporary anesthetic circuits and most rebreathing bags are not reactive with inhalants
7. Halothane, isoflurane, and desflurane are stable in moist soda lime
   a. Sevoflurane produces a potentially toxic substance called Compound A when it comes into contact with dry soda lime but modern absorbents have reduced this concern
   b. Carbon monoxide (CO) is formed when desflurane, enflurane, and isoflurane comes into contact with dry soda lime. In contrast, a smaller but significant CO formation occurs with sevoflurane.

Elimination of Inhalant Anesthetic Drugs

I. Pulmonary

A. Inhalants are primarily excreted unchanged via the lungs

B. Factors that affect the rate of anesthetic uptake are important in anesthetic elimination
   1. Pulmonary ventilation
   2. Blood flow
   3. Solubility of the inhalant anesthetic in blood and tissue

C. Ventilation (breathing) eliminates the inhalant anesthetic from the lung and the arterial blood tension (partial pressure) decreases. This is followed by the tension in tissues; because of the high blood flow to the brain, the inhalant tension falls rapidly and accounts for the rapid awakening from anesthesia.

1. Inhalant anesthetics that are comparatively less soluble in blood such as sevoflurane and desflurane are eliminated rapidly; the decrease in inhalant concentration from other tissues is progressively slower and is dependent on blood flow

Biotransformation of Inhalant Anesthetic Drugs To Metabolites

Agent	% Recovered as Metabolite
Nitrous oxide	0.004
Desflurane	0.02
Isoflurane	0.25
Sevoflurane	3.0-5.0
Halothane	20.0

II. Other routes through which small quantities of inhalants may be excreted are skin, milk, mucous membranes, and urine. Biotransformation-inhalants are metabolized in the body to varying degrees (See Table 9-2).

A. Metabolism is generally by hepatic microsomal enzyme systems; various intermediate metabolites are formed; these may be responsible for toxic effects

TABLE 9-2 Degrees Of Metabolism and Principal Metabolites of Inhalant Anesthetic Drugs in Humans

Degree of metabolism* (%)		Mechanism of metabolism	Principal metabolites
Halothane	20-45	Hepatic cytochrome P450 (2A6, 2E1, 3A4)	Trifluoroacetic acid, Cl ion, bromide ion
Isoflurane	0.2	Hepatic cytochrome P450 (2E1, 3A)	Trifluoroacetic acid, trifluoroacetaldehyde, trifluoroacetyl chloride
Sevoflurane	3-5	Hepatic cytochrome P450 (2E1)	Hexafluoroisopropanol, fluoride ion
Desflurane	0.02	Hepatic cytochrome P450 (2E1, 3A)	Trifluoroacetic acid, fluoride ion, carbon dioxide, water
Nitrous oxide	0.004	Intestinal bacteria (*Escherichia coli*)	Nitrogen, inactivated methionine synthase, reduced cobalamin (vitamin B_{12})

*Degree of metabolism includes estimates from recovery of metabolites and estimates from recovery of the unchanged drug.

1. About 0.2% of isoflurane is metabolized compared with 2% to 5% of sevoflurane, and 0.2% of desflurane
   a. Halothane is metabolized in excess of 20% of an administered dose
2. Toxic metabolites are primarily inorganic fluoride and bromide ions

IV. Diffusion hypoxia may occur at the end of anesthesia: the rapid elimination of N_2O from the blood into the alveoli results in the dilution of alveolar oxygen (O_2) by N_2O and subsequent hypoxemia if ventilation is not maintained

Potency of Inhalants: Minimum Alveolar Concentration

I. The potency of inhalants can be expressed in several ways; one method is to determine the minimum alveolar concentration (MAC) of the inhalant; MAC is generally defined as the minimum alveolar concentration of an inhalant (1 atm) that produces no response in 50% of animals exposed to a painful (noxious) stimulus (See Table 9-3)

A. MAC is generally measured as the end-tidal concentration of an inhalant
B. MAC values are not vaporizer settings; MAC values are alveolar concentrations at equilibrium and are lower than the vaporizer setting due to tissue uptake
C. MAC values are a clinically useful method for comparing the potency of inhalant anesthetics
   1. MAC is conceptually similar to the effective dose required to produce anesthesia in 50% of animals exposed to a painful (noxious) stimulus (ED50) when administering an injectable anesthetic

TABLE 9-3 Minimum Alveolar Concentrations (MAC) of Inhalant Anesthetic Drugs

Agent	Human	Dog	Cat	Horse
Halothane	0.76	0.87	1.19	0.88
Isoflurane	1.2	1.3	1.63	1.31
Sevoflurane	1.93	2.34	2.58	2.34
Desflurane	6.99	7.20	9.80	7.23
Nitrous oxide*	101.1	188-297	255	190

*Nitrous oxide cannot produce anesthesia by itself in animals.

II. MAC values vary among species and are affected by:
- A. Age: older animals have a reduced inhalant requirement
- B. Body weight: smaller animals may have an increased inhalant requirement
- C. Increased metabolic rate and stress increase inhalant requirement
  1. Removal of stress does not immediately reverse the increase in MAC implying residual metabolic effects
- D. Temperature: hypothermia reduces the inhalant requirement
- E. Administering other CNS-depressant drugs (opioids, sedatives) reduces the inhalant requirement
- F. Disease:
  1. Hyperthyroidism or hypothyroidism
  2. Hypovolemia, anemia
  3. Septicemia
  4. Extreme acid-base imbalances
  5. Pregnancy
- G. The duration of anesthesia, acid-base changes, and the partial pressure of O_2 do not alter MAC values

III. MAC values correlate with anesthesia:
- A. 1 MAC produces light anesthesia
- B. 1.5 MAC is generally considered surgical anesthesia
- C. 2 MAC produces deep anesthesia
- D. Animals awaken after anesthesia at approximately 0.5 MAC

Increasing or Decreasing Inhalant Anesthetic Concentrations

Increasing
Turn up O_2 flow
Turn up vaporizer
DO NOT activate O_2 flush valve

Decreasing
Turn up O_2 flow or activate flush valve
Turn vaporizer down or off

Specific Inhalant Anesthetic Drugs (See Table 9-4)

I. Isoflurane (IsoFlo, Isovet)
- A. General anesthetic properties
  1. Relatively low blood-gas solubility coefficient: 1.45
  2. A halogenated ether that is stable without the need for preservatives

TABLE 9-4 Summary of Physiochemical Properties of Inhalation Agents

Properties	Ether	Nitrous oxide	Halothane	Isoflurane	Sevoflurane	Desflurane
Molecular weight	74	44	197.4	185	200	168
Specific gravity (g/mL)	0.72	1.53	1.87	1.52	1.52	1.47
Odor	Pungent, unpleasant	Pleasant	Sweet, pleasant	Pungent	Pleasant	Pungent
Preservative	Necessary	None	Necessary (thymol)	None	None	None
Stability	May react	Nonreactive	Corrodes aluminum, brass, lead with moisture	Nonreactive	Stable	Nonreactive
To metal						
To alkali	Stable (traces of aldehydes)	Stable	Decomposes slightly	Stable	Decomposes	Stable
To ultraviolet light	Ignitable	Stable	Decomposes	Stable	Stable	Stable
To other	Avoid halogens	Does not react with other anesthetics	Decomposes rubber (softens and swells)	—	—	More stable in rubber than other volatile anesthetics
Reaction with CO_2 absorbents						
Carbon monoxide	—	—	Least occurrence	Occurs	Least occurrence	Greatest occurrence
Compound A	—	—	Occurs with a closed-circle breathing system	None	Occurs	Occurs
Heat	—	—	Occurs	Occurs	Occurs	Occurs
Explosiveness	Explosive (in air or oxygen)	None	None	None	None	None
Presentation at room temperature	Colorless liquid	Colorless gas (liquid under pressure)	Colorless liquid	Colorless liquid	Colorless liquid	Colorless liquid

3. Produces comparatively rapid induction and recovery from anesthesia
4. MAC of approximately 1.3
5. Can be used in all species

B. Effects on organ systems
   1. Nervous system
      a. Produces generalized, dose-dependent CNS depression
      b. Cerebral blood flow is not increased if normal ventilation is maintained
      c. Burst suppression on the electroencephalogram is observed in moderate to deep surgical anesthesia
   2. Respiratory system
      a. Produces clinically significant respiratory depression
      b. Tidal volume increases initially with depth of anesthesia; respiratory rate decreases
      c. Hypoventilation (increased $PaCO_2$) increases with time and increasing concentrations
         (1) Surgical stimulation increases respiration and may prevent a large rise in $PaCO_2$
      d. Ventilation may need to be assisted or controlled especially in large animals
   3. Cardiovascular system
      a. Cardiovascular depression is dose dependent
      b. Hypotensive: mean arterial blood pressure and peripheral vascular resistance decrease with increasing depth of anesthesia; skin and muscle blood flow may increase
         (1) Hypotension is initially caused by vasodilatation but is augmented by decreased myocardial contractile performance when excessive inhalant anesthetic concentrations are delivered
      c. Cardiac contractility is depressed less than with halothane
         (1) Cardiac output is usually maintained at concentrations producing surgical anesthesia
      d. Isoflurane does not sensitize the heart to catecholamine-induced arrhythmias
   4. Gastrointestinal system
      a. Smooth muscle tone and motility are decreased
      b. No hepatotoxicity reported (metabolism is minimal)
   5. Renal system
      a. Renal blood flow is dose-dependently and reversibly depressed

   b. Minimal postanesthetic changes in renal function reported; very little metabolism
6. Muscular system
   a. Excellent muscle relaxation
   b. Potentiates nondepolarizing neuromuscular blocking drugs
   c. Unlikely to induce malignant hyperthermia in swine
7. Uterus and fetus
   a. Rapidly crosses the placental barrier thereby depressing the fetus
   b. Reduces uterine tone

C. Absorption, fate, and excretion
1. Absorbed and eliminated via the alveoli
2. Primarily eliminated unchanged by the lungs
3. Very little biodegradation; approximately 0.25% is metabolized to inorganic fluoride (trifluoroacetic acid)

D. Clinical use
1. Produces fast, smooth induction and recovery from anesthesia in all species tested
2. Rapid recovery may predispose some animals to emergence delirium
3. Calibrated, thermocompensated vaporizers should be used to deliver accurate concentrations
4. Compatible with N_2O
5. Can be used for mask induction; irritating odor may inhibit respiration and cause bronchoconstriction in some animals

E. Dose
1. Induction: 2.5% to 5% is usually required
2. Induction can be facilitated by the use of N_2O or intravenous anesthetics
3. Maintenance: 1% to 3%

Useful Facts ▪ Isoflurane

- Potent anesthetic
- Fast and smooth induction and recovery
- Easy to control
- Less cardiac depression than halothane
- Very low metabolism
- Less expensive than sevoflurane or desflurane
- More respiratory depression than halothane
- Produces CO when exposed to dessicated CO_2 absorbent material

II. Sevoflurane (Ultane, Sevorane, Sevoflo)
- A. General anesthetic properties
  1. Low blood-gas partition coefficient: 0.5 to 0.7
     a. Rapid, smooth induction; rapid recovery (faster than isoflurane)
  2. MAC of approximately 2.4
  3. Can be used in all species
  4. Not pungent, may be better than isoflurane for mask induction, especially in cats
- B. Effects on organ systems: Similar to isoflurane
  1. Nervous system
     a. Similar to isoflurane
     b. Dose-dependent CNS depression; no convulsive activity
  2. Respiratory depression similar to or greater than isoflurane
  3. Dose-dependent cardiorespiratory depression
     a. Does not sensitize the heart to catecholamine-induced cardiac arrhythmias
  4. Gastrointestinal system: decreases smooth muscle tone and motility
  5. Renal system
     a. Liver biotransformation produces fluoride ion but the levels are not nephrotoxic
     b. Can be degraded by CO_2 absorbents to produce compound A (no clinical significance with modern absorbents)
  6. Muscular system
     a. Produces good muscle relaxation
     b. Can trigger malignant hyperthermia
  7. Uterus and fetus
     a. Rapidly crosses the placenta, producing fetal depression
- C. Absorption, fate, excretion
  1. Absorbed and eliminated by the lung
  2. Minimally metabolized by the liver (3%); produces inorganic fluoride similar to isoflurane
- D. Clinical use
  1. Induction and recovery from anesthesia is generally faster than with isoflurane because of lower blood-gas partition coefficient; however, lower potency requires higher vaporizer settings
  2. Produces good muscle relaxation and anesthesia
  3. Can be used for mask induction

4. Recovery may be rapid especially following short duration anesthesia; emergence delirium can occur

E. Dose
1. Mask induction: 5% to 7% concentrations
2. Maintenance: 3% to 4%

Useful Facts ▪ Sevoflurane

- Similar to isoflurane
- More rapid induction and recovery than isoflurane

III. Desflurane (Suprane)

A. General anesthetic properties
1. Similar in structure to isoflurane with fluorine substituted for chlorine
2. Extremely low blood-gas partition coefficient (0.42); comparatively rapid induction and recovery
3. Less potent than other halogenated agents; MAC is approximately 7.2%
4. Pungent; produces airway irritation, provoking coughing and breath holding
5. Requires a special, electrically heated vaporizer for safe administration

B. Effects on organ systems
1. Similar to isoflurane
2. Nervous system
   a. Similar to isoflurane
   b. Dose-dependent CNS depression
   c. Good muscle relaxation; enhances nondepolarizing neuromuscular blocking drugs
3. Respiratory system
   a. Dose-dependent respiratory depression; decreases the breathing response to increases in $PaCO_2$
   b. Pungent odor irritates the airway; induction to anesthesia may be difficult unless preceded by an adequate preanesthetic medication
4. Cardiovascular system
   a. Qualitatively and quantitatively similar to isoflurane
   b. Can cause sympathetic activation "sympathetic storm" in some animals

5. Gastrointestinal system: decreases smooth muscle tone and motility
6. Renal system: does not affect postoperative renal function
7. Muscular system
   a. Produces good muscle relaxation
   b. Can trigger malignant hyperthermia in swine
8. Uterus and fetus
   a. Crosses the placental barrier; causes fetal depression
   b. Allows rapid recovery (fetus) from anesthesia because of low blood-gas partition coefficient

C. Absorption, fate, excretion
1. Absorbed and eliminated by the lung
2. Minimally metabolized by the liver; produces less inorganic fluoride than isoflurane
3. No hepatotoxicity or nephrotoxicity

D. Clinical use
1. Induction and recovery from anesthesia is approximately twice as fast as with isoflurane because of the extremely low blood-gas partition coefficient (0.42), despite comparatively low potency (MAC ≈ 7.2%)
2. Produces good muscle relaxation and analgesia
3. Pungent odor makes mask induction difficult unless appropriate preanesthetics are used
4. Recovery may be so rapid that re-sedation is needed to avoid emergence delirium
5. Doses
   a. Mask induction: 10% to 15%
   b. Maintenance: 6% to 9%
   c. Use of preanesthetic drugs, N_2O, and sedatives and analgesics (fentanyl) can reduce drug requirement

Useful Facts ▪ Desflurane

- More rapid induction and recovery than isoflurane or sevoflurane
- May cause tachycardia and airway irritability
- Has been shown to react with the CO_2 absorbent in anesthesia circuits to produce detectable levels of CO

IV. N_2O

A. General anesthetic properties
1. A gas at room temperature, but compressible at 30 to 50 atm (750 psi) to a colorless liquid; returns to gaseous state when released from the cylinder

2. Does not produce anesthesia in animals; low potency: MAC is 200-300
3. Nonflammable, but supports combustion

B. Effect on systems
1. Nervous system
   a. Analgesic and minimal anesthetic action produced by cerebrocortical depression
      (1) Analgesia is produced when N_2O is delivered at more than 30% of the inspired gas concentration; N_2O is usually delivered at 50% to 70% of the inspired gas concentration
   b. Dangerous in excessive concentrations (more than 70% total gas flow) because this could interfere with oxygenation
2. Respiratory system
   a. Does not irritate the respiratory tract
   b. Causes minimal respiratory depression
3. Cardiovascular system
   a. Produces minimal augmentation of myocardial function
   b. Does not sensitize the myocardium to catecholamines
4. Other organ systems
   a. Ileus may occur following prolonged anesthesia due to gas accumulation within the gastrointestinal tract
   b. Does not cause muscle relaxation
   c. Crosses placental barrier (may cause fetal hypoxemia)

C. Absorption, fate, and excretion
1. Readily crosses alveolar membranes because of the low blood-gas partition coefficient (0.49) and comparatively large inspired concentrations (30% to 70%)
2. May accelerate the uptake of the concurrently administered inhalant (second gas) into the blood (second-gas effect); the enhanced uptake of the second gas (e.g., isoflurane) is caused by an N_2O-dependent increase in alveolar ventilation
3. Diffuses into closed air cavities (e.g., gas bubbles [gut; air embolus in blood]; pneumothorax (Fig. 9-4): N_2O is 30 times more soluble in blood than nitrogen; it diffuses into air-containing cavities faster than nitrogen diffuses out; if the cavity is closed (e.g., pneumothorax, obstructed bowel, air embolism, blocked paranasal sinuses) and N_2O is administered, either the volume or pressure inside the closed cavity increases

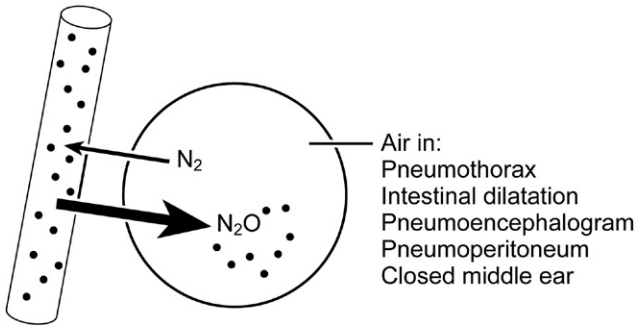


FIG. 9-4. Nitrous oxide (N_2O) is comparatively much less soluble in blood than isoflurane or sevoflurane (low blood gas partition coefficient) and will diffuse from the blood to air-or gas containing cavities increasing volume and/or the pressure in closed body cavities.

4. Diffusion hypoxia is a result of the low blood-gas partition coefficient of N_2O; rapid diffusion of N_2O into the alveoli at the end of anesthesia dilutes the O_2 in the alveoli; alveolar O_2 tension decreases; hypoxia is prevented by administering high O_2 flow rates for 5 to 10 minutes after discontinuing N_2O
5. Evidence suggests some biotransformation; bone marrow depression may occur after prolonged exposure

D. Clinical use
1. Need for higher fresh-gas flow rates and potential side effects (hypoxia) limit its use
2. Additive with other inhalants (50% to 70% of inspired gas concentration); less of the other inhalant is needed to produce general anesthesia; cannot be used alone because of its low anesthetic potency in animals
3. The ratio of N_2O to O_2 delivered by the anesthetic machine must be continually monitored; no more than 70% N_2O should be used

Useful Facts ▪ Nitrous Oxide

- Hastens induction to anesthesia (second-gas effect)
- Additive with inhalant anesthetics
- Administered to improve analgesia
- Minimal cardiorespiratory effects
- Does not serve as a source of oxygen

V. Halothane
- A. General anesthetic properties
  1. Relatively low blood-gas solubility coefficient: 2.54
  2. A halogenated hydrocarbon with thymol as a stabilizing agent
     a. Thymol can accumulate in halothane vaporizers and influence their accuracy
  3. Produces comparatively slower induction and recovery from anesthesia than isoflurane, sevoflurane, and desflurane
  4. MAC is approximately 0.9
  5. Can be used in all species
- B. Effects on organ systems
  1. Nervous system and musculoskeletal
     a. Dose dependent depression of the CNS
     b. Increases cerebral blood flow
     c. Muscle relaxation is only moderate during light anesthesia
     d. Malignant hyperthermia (a genetic muscle defect) can be triggered in susceptible people, swine, dogs, and cats
  2. Respiratory system
     a. Minute volume is minimally decreased during anesthesia, but breathing is usually adequate
        (1) Less of a respiratory depressant than isoflurane or sevoflurane
  3. Cardiovascular system
     a. May cause bradycardia at clinical concentrations
     b. Hypotension is related to the depth of anesthesia and caused by a decrease in myocardial contractile performance at low concentrations and both decreased myocardial contractile performance and vasodilatation at high concentrations
     c. Sensitizes the heart to catecholamine-induced arrhythmias
  4. Uterus and fetus
     a. Decreases uterine tone; may slow uterine involution postpartum
     b. Readily crosses the placental barrier
- C. Absorption, fate, and excretion
  1. Halothane (20% to 40% inspired amount) is metabolized by liver microsomes; trifluoroacetic acid, bromide, and

chloride radicals are produced and excreted in the urine for many hours to days

D. Clinical use
   1. Produces good muscle relaxation and anesthesia
   2. Can be used for mask induction
   3. Recovery may be rapid, especially following short duration anesthesia; emergence delirium can occur

E. Dose
   1. Mask induction: 2% to 4% concentrations
   2. Maintenance: 0.5% to 2%
   3. Halothane is no longer available for clinical use in the United States but is available in other countries

F. Maintenance: 0.5% to 1.5% in small animals; 1% to 2% in large animals

Cautions ▪ Halothane

- Sensitizes the heart to catecholamines
- Significant myocardial depressant
- Liver dysfunction can occur or worsen (more than 20% metabolized)
- Can trigger malignant hyperthermia (especially in pigs)

VI. Diethyl ether

A. Ether was once a frequently used inhalant anesthetic; it is now occasionally used in laboratory animals

B. Highly flammable and explosive

C. An ideal anesthetic in some respects because it maintains respiration and minimally depresses cardiac output

D. May cause salivation, nausea, and vomiting during induction and recovery

E. Most frequent use in clinical practice today is to make bandage tape sticky

Inhalant Anesthetic and Gas Toxicity

I. The anesthetic molecule is nontoxic; however, volatile anesthetics are not completely inert and are metabolized to varying degrees (except for N_2O)

A. Metabolites are believed to be responsible for drug toxicity
   1. Metabolism of inhalant anesthetics occurs primarily in the liver; metabolites are excreted predominantly by the kidneys

2. Defluoridation of isoflurane and desflurane does not result in clinically significant concentrations of serum fluoride ions
3. Metabolism of sevoflurane may result in higher fluoride concentrations, but they seldom reach the threshold for nephrotoxicity

B. Chloride, bromide, and fluoride metabolites have been reported

C. Inhalant anesthetics interact with CO_2 absorbents (barium hydroxide lime, soda lime) to produce potentially toxic metabolites and heat (Fig. 9-5)
   1. Isoflurane—CO
      a. Volatile agents containing a difluoromethoxy moiety (CHF_2) may react with the absorber to form CO; the magnitude of CO production is greatest with desflurane, intermediate with isoflurane, and least with halothane and sevoflurane
      b. To reduce the accumulation of CO in circle and to-and-fro systems, inhalant anesthetics should not be used with dry CO_2 absorbent

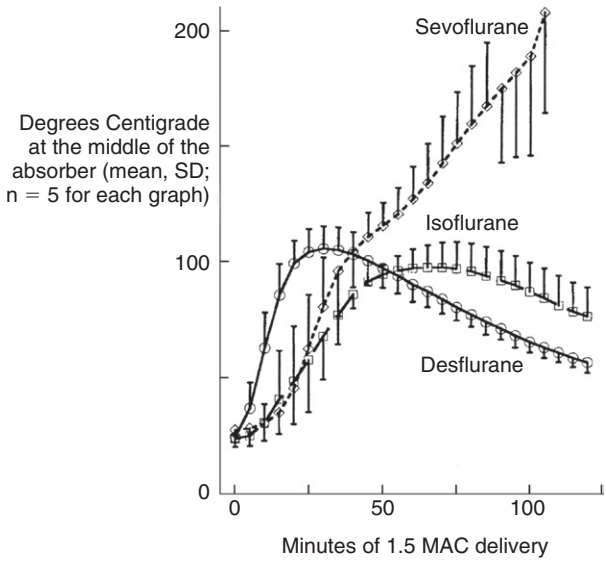


FIG. 9-5. Inhalant anesthetics react chemically with carbon dioxide absorbents producing heat. Temperatures recorded within the carbon dioxide (CO_2) absorbent canister during inhalation anesthesia.

2. Sevoflurane—compound A and heat
   a. Sevoflurane may react with CO_2 absorbents (especially barium hydroxide lime) and be degraded to haloalkenes and compound A, which are nephrotoxic
   b. The interaction of desiccated absorbents with inhalant anesthetics can produce absorbent temperatures of several hundred degrees C (see Fig. 9-5)
3. Desflurane and isoflurane can increase the temperature up to about 100° C (212° F) with barium hydroxide lime
   a. Sevoflurane can increase the temperature up to 350° C to 400° C (662° F to 752° F) with barium hydroxide lime; melting of plastic components, smoldering, fires, and explosions have been reported

D. Low-flow anesthesia increases the possibility of interactions between volatile anesthetics and CO_2 absorbents; barium hydroxide lime should not be used for low-flow anesthesia with isoflurane and sevoflurane

IV. N_2O toxicity

A. N_2O is not metabolized in vivo

B. Clinical use is not associated with any direct toxic effects

V. O_2 toxicity

A. Exposure of animals to elevated O_2 tensions at atmospheric pressures for prolonged periods (100% for 12 hours, more than 46% for more than 24 hours) causes metabolic derangements potentially resulting in pulmonary dysfunction; changes include decreases in vital capacity, lung compliance, minute ventilation, respiratory rate, pH, arterial O_2 partial pressure, total lung volume, and CO_2-diffusing capacity

B. Animals show considerable variation in the susceptibility to O_2 toxicity

C. The rate of onset of the disease process is proportional to the inspired tension of O_2, the duration of exposure and the production of free radicals
   1. Free radicals are active products of this process: superoxide anion (O_2^-), the hydroxyl radical (OH^-), and hydrogen peroxide (H_2O_2)

D. Reductions in vital capacity and pulmonary compliance are the best criteria for identifying the onset of toxicity

E. Safety range is 18% to 25%

10 Neuromuscular Blocking Drugs

"Don't fight forces, use them."
R. BUCKMINSTER FULLER

OVERVIEW

Neuromuscular blocking drugs (NMBDs), referred to as *peripheral muscle relaxants*, in contrast to centrally acting muscle relaxants such as guaifenesin or diazepam, interfere with or block neuromuscular transmission at the motor end plate. They are useful adjuncts to general anesthesia because they provide short-term or reversible skeletal muscle relaxation. NMBDs do not provide analgesia, sedation, amnesia, or hypnosis, and they predispose the animal to hypothermia. Animals are unable to breathe, necessitating controlled ventilation and constant monitoring.

General Considerations

I. The primary pharmacologic effect of peripheral NMBDs is to produce skeletal muscle (SM) relaxation
II. NMBDs are potentiated by many other drugs
  A. Volatile anesthetic agents
    1. Order of potentiation: desflurane > sevoflurane > isoflurane > halothane > nitrous oxide
  B. Aminoglycoside antibiotics
  C. Local anesthetics
  D. Cardiac antiarrhythmic drugs
  E. Diuretics
  F. Magnesium
III. Other factors that may influence the effects of NMBDs
  A. Hypothermia
  B. Acid-base alterations
  C. Changes in serum potassium concentration
  D. Adrenocortical dysfunction
  E. Thermal (burn) injury
IV. Potential mechanisms of SM relaxation

A. NMBDs interfere with cholinergic (nicotinic) neuromuscular transmission in the peripheral somatic nervous system
B. Some NMBDs enhance the activity of endogenous inhibitory mechanisms in the central nervous system, which normally modulate SM tone

V. NMBDs are used adjunctively during anesthesia to produce controlled muscle relaxation

VI. NMBDs produce muscle relaxation but do not produce analgesia or unconsciousness

VII. NMBDs produce respiratory paralysis, which necessitates manual or mechanical ventilation support

VIII. Hypothermia is an important secondary effect of prolonged SM relaxation

IX. NMBDs are positively charged (ionized) and therefore do not pass the blood-brain barrier or cross the placenta in significant amounts

X. Various electrical stimulators and stimulation protocols can be used to determine the degree of neuromuscular blockade (Figs. 10-1 and 10-2)

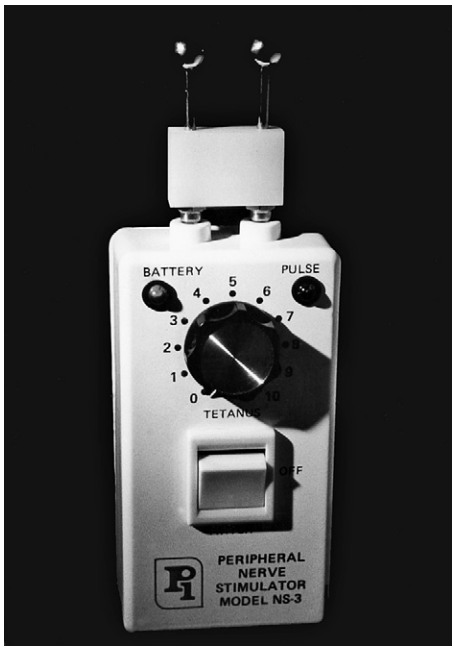


FIG. 10-1. Peripheral nerve stimulators are used to test for the adequacy of neuromuscular blockade.

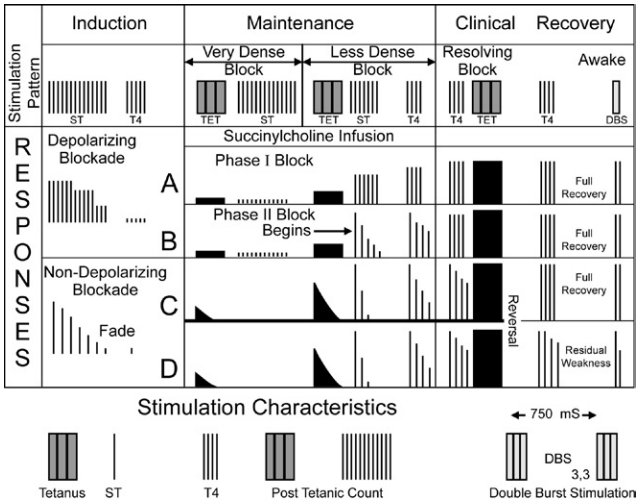


FIG. 10-2. Assessing neuromuscular function. Diagram simulates the clinical responses observed after neuromuscular stimulation. Stimulation patterns are depicted in the upper panel. DBS, double burst-stimulation; ST, single twitch; T4, train of four; TET, tetanus. The following four situations are demonstrated by the letters: *A*, The administration of succinylcholine produces Phase 1 (depolarizing) block; *B*, the development of a phase II block. Phase II block is a complex phenomena caused by continuous exposure to depolarizing drugs and results in long term neuromuscular blockade; *C*, a nondepolarizing blockade can be reversed with full recovery; and *D*, a nondepolarizing blockade that demonstrates residual weakness. (From Barash PG, Cullen BK, Stoelting RK: *Clinical Anesthesia*, ed 2, Philadelphia, JB Lippincott, 1992).

A. Nondepolarizing neuromuscular blockade (see below) is monitored by nerve stimulation and more specifically by introducing a train of four (TOF) stimuli (see Chapter 14)
   1. Method used to objectively monitor degree of chemical paralysis
   2. Used to determine correct dosage or infusion rate
   3. The number of responses to the TOF stimuli indicates the degree of neuromuscular blockade

Normal Neuromuscular Function

I. Acetylcholine (ACh) is released in small amounts, even in resting muscles
   A. Random ACh release causes mini-endplate potentials at the postsynaptic muscle membrane, which help to maintain muscle tone but are insufficient to evoke muscle contraction

II. Action–potential-dependent ACh release

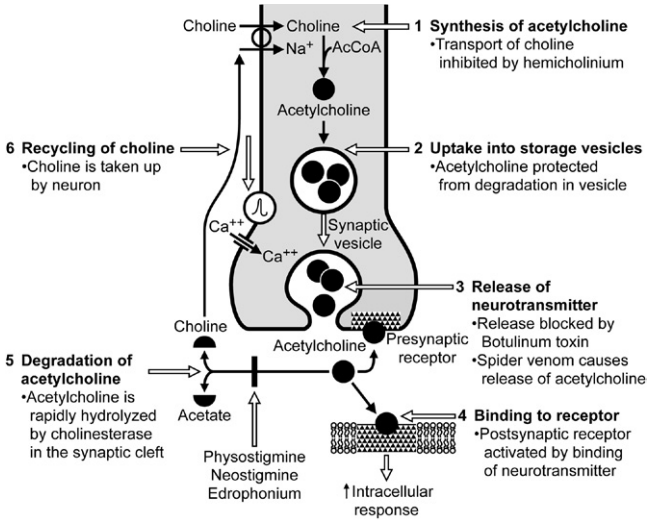


FIG. 10-3. Synthesis, release reuptake, degradation and binding of acetylcholine at the neuromuscular junction. Physostigmine, neostigmine and edrophonium are acetylcholine esterase inhibitors that block acetylcholine metabolism and reverse nondepolarizing neuromuscular blocking drug (pancuronium, rocuronium) effects.

A. Nerve impulses (action potentials) cause large depolarization in nerve terminals of α-motor neurons
B. Depolarization in the presence of extracellular Ca^{++} causes simultaneous fusion of many ACh-containing vesicles with the terminal nerve membrane (Fig. 10-3)
C. Release of ACh packets (quanta) evokes a large endplate potential, leading to muscle contraction

III. Combination of ACh with postjunctional nicotinic receptors (Nm receptors)
A. Receptors on the muscle endplates are nicotinic, type IV cholinergic (Nm) receptors
B. Strength of muscle contraction is proportional to the number of receptors activated by ACh

IV. The duration of ACh activity at any cholinergic synapse is limited by the action of acetylcholinesterase (ACh esterase); ACh is metabolized to acetic acid plus choline at the synaptic cleft
A. Choline produced by hydrolysis of ACh is taken up by the nerve terminals and resynthesized into ACh at the nerve terminal membrane
B. ACh is packaged into vesicles or stored freely in the cytoplasm of the nerve terminals

Mechanisms of Skeletal Muscle Relaxation Evoked by Interference with Normal Peripheral Neuromuscular Function

- **I.** At presynaptic sites
  - A. Inhibition of ACh synthesis (e.g., hemicholinium blocks choline uptake)
  - B. Inhibition of ACh release
    1. Ca^{++} deficiency, Mg^{++} increases
    2. Procaine
    3. Tetracyclines and aminoglycoside antibiotics
    4. Some β-blockers
    5. Botulinum toxin
- **II.** At postsynaptic sites
  - A. Persistent depolarization with an agonist that has a longer duration of action than ACh (e.g., succinylcholine chloride)
  - B. Competitive block of ACh receptors causing nondepolarizing blockade (e.g., curare, edrophonium, atracurium)

Types of Neuromuscular Blocks

- **I.** Phase I block: depolarizing block (succinylcholine)
- **II.** Phase II block: nondepolarizing block (atracurium)
- **III.** Mixed block: any combination of I and II
- **IV.** Dual block: excessive amounts of depolarizing agents producing phase II block
- **V.** Nonacetylcholine block (procaine, botulinum, decreased Ca^{++}, increased Mg^{++}, increased K^{+}, decreased K^{+})

Muscle Relaxation Sequence

- **I.** First to last: Oculomotor muscle (m.) → palpebral m., facial m. → tongue and pharynx → jaw and tail → limbs → pelvic m.→ caudal abdominal m. → cranial abdominal m. → intercostal m. → larynx → diaphragm
  - A. The sequence of motor blockade is highly variable
    1. Intercostal and diaphragmatic muscles are thought to be affected last but the clinical return of functional motor function is highly variable
  - B. Motor activity to the limbs may appear to return (twitching, jerking) before the diaphragm is fully functional
- **II.** Recovery is generally in the reverse order of paralysis
- **III.** It is possible but difficult to titrate the dose of a specific NMBD to paralyze the muscles of the eye while maintaining diaphragmatic function

Specific Neuromuscular Blocking Drugs (Tables 10-1 and 10-2)

I. Depolarizing drugs act like ACh
- A. Succinylcholine chloride (Sucostrin, Anectine, Suxamethonium)

II. Nondepolarizing drugs; curare-like competitive blocking drugs
- A. Pancuronium bromide (Pavulon)
- B. Atracurium besylate (Tracrium)
- C. Cisatracurium (Nimbex)
- D. Vecuronium bromide (Norcuron)
- E. Rocuronium (Zemuron, Esmeron)
- E. Mivacurium chloride (Mivacron)
- F. Pipecuronium (Arduan)

Clinical Differentiation Between Depolarizing and Nondepolarizing Drugs

I. Depolarizing
- A. First: transient muscle fasciculations caused by asynchronous depolarization
- B. Second: paralysis caused by prolonged depolarization of the motor endplate
- C. Paralysis is not reversed by anticholinesterase drugs
- D. Paralysis is terminated by metabolism of the NMBD by pseudocholinesterase

II. Nondepolarizing
- A. No muscle fasciculation occurs before muscle paralysis, and there is no depolarization of motor endplate; the animal gradually relaxes or "fades"
- B. Effects can be reversed by anticholinesterase (acetylcholineesterace inhibitors) drugs or by Sugammadex (see Fig. 10-3)
  1. Neostigmine
  2. Pyridostigmine
  3. Pyridostigmine
  4. Edrophonium
  5. Sugammadex reverses neuromuscular blockade caused by rocuronium
     - a. Sugammadex, a selective relaxant binding agent (SRBA), is a modified γ-cyclodextrin, with a lipophilic core and a hydrophilic periphery. Sugammadex's binding encapsulation of rocuronium within a lipophilic core

TABLE 10-1 Dose Of Neuromuscular Blocking Drugs with Side Effects and Contraindications

Agent	Species	Dose Intravenously (mg/kg)	Duration of Action (min)	Side Effects	Contraindications
Succinylcholine chloride	Dog	0.3-0.4	1-38	Little cardiovascular effect; muscarinic effect is bradycardia; nicotinic effects are hypertension, increased intraocular pressure; hyperpyrexia	Organophosphate anthelmintics, chronic liver disease, malnutrition, high-K^+, glaucoma, penetrating eye injury
	Cat	3-5 (total)	2-6		
	Pig	0.75-2	1-3		
	Horse	0.1-0.33	1-10		
Pancuronium bromide	Dog	0.02-0.06	15-108	Negligible	Liver or kidney disease
	Cat	0.02-0.06	14-15		
	Pig	0.07-0.12	7-30		
	Horse	0.08-0.14	16-35		
	Cattle	0.1	30-40		
	Calf	0.04	26		
	Sheep	0.005	21		
Vecuronium	Dog	0.01-0.2	10-42	Negligible	
	Cat	0.02-0.04	5-9		
	Pig	0.1-0.2	5-20		
	Horse	0.1	20-40		
	Sheep	0.004	14		
Atracurium	Dog	0.1-0.4	10-30		
	Cat	0.1-0.25	10-15	Negligible	
	Pig	0.5-2.5	10-60		
	Horse	0.07-0.09	8-24	Negligible	
	Sheep	6 μg/kg/hr			
	Llama	0.15	6		
Cisatracurium	Dog	0.02-0.1	10-30	Negligible	
Rocuronium	Dog	0.3-0.6 mg/kg	20-30 min	Negligible	
Pipecuronium	Dog	70-90 μg/kg	16-81	Occasional hypotension	
	Cat	40-60 μg/kg	17-24		

TABLE 10-2 Autonomic Effects of Neuromuscular Blocking Drugs

Drug	Autonomic Ganglia	Cardiac Muscarinic Receptors	Histamine Release
Succinylcholine	Stimulated	Stimulated	Slight
Pancuronium	None	Weakly blocked	None
Atracurium	None	None	Slight
Cisatracurium	None	None	None
Vecuronium	None	None	None
Rocuronium	None	None	None
Mivacurium	None	None	Slight
Pipecuronium	None	None	None

renders it unavailable to bind to the acetylcholine receptor at the neuromuscular junction.

III. Onset of effect
- A. Rapid (less than 1 minute): succinylcholine
- B. Medium (1 to 2 minutes): atracurium, cisatracurium, mivacurium, vecuronium
- C. Slow (3 to 5 minutes): pancuronium

IV. Duration of effect (dependent on dose)
- A. Ultrashort (1 to 3 minutes): succinylcholine
- B. Intermediate (10 to 30 minutes): atracurium, cisatracurium, rocuronium, vecuronium
- C. Long (>30 minutes): mivacurium, pancuronium, pipecuronium

V. Speed of antagonism by anticholinesterases
- A. Rapid (less than 1 minute): mivacurium
- B. Medium (1 to 2 minutes): atracurium, vecuronium
- C. Slow (3 to 5 minutes): pancuronium

VI. Metabolism
- A. Hofmann elimination: atracurium, cisatracurium
- B. Plasma cholinesterase: mivacurium, succinylcholine
- C. Liver: atracurium, cisatracurium, pancuronium, pipecuronium, vecuronium

Depolarizing Blocking Drugs

I. Mechanism of action
- A. Persistent depolarization alone may result in neuromuscular block because of Na^{++} inactivation, which prevents electrical impulse generation

1. Succinylcholine is used as a "capture" drug for exotic species because of its rapid onset of effect, short duration of action and effectiveness after intramuscular administration. It should only be used by experienced individuals.

B. Dual block: prolonged exposure of ACh membrane receptors to large doses of depolarizing drugs (ACh, succinylcholine) reduces the ability of these drugs to cause conductance changes; the reason for this is uncertain

II. Indications

A. Diagnostic or surgical procedures requiring a short duration of muscle relaxation
B. Facilitation of endotracheal intubation
C. Cesarean section (drugs do not cross placental barrier)
D. Fracture reduction
E. Ophthalmologic procedures

III. Contraindications with depolarizing drugs

A. Disease states causing prolonged NMBD activity
   1. Liver disease: pseudocholinesterase is produced in the liver
   2. Chronic anemia: acetylcholinesterase is associated with red blood cell membranes
   3. Chronic malnutrition
   4. Organophosphates (anthelmintics): enzyme activity is inhibited

B. Other conditions
   1. High serum K^+ levels
      a. Burns, muscle trauma, renal failure
      b. Depolarizing blockade can cause potassium release from muscles
   2. Ophthalmologic conditions
      a. Glaucoma, penetrating eye wounds
      b. Depolarizing blockade can transiently increase intraocular pressure

---

NOTE: Organophosphorous parasiticides form an irreversible bond with the pseudocholinesterase and recovery only occurs after generation of new enzyme. Poisoning results in salivation, sweating, bradycardia, bronchospasm and muscle weakness. Treat with atropine.

IV. Succinylcholine: adverse effects (see Table 10-2)

A. Adverse side effects are related to skeletal muscle depolarization, autonomic activity (bradycardia) and anaphylaxis (rarely)

1. Muscle soreness: reason unknown; probably related to muscle fasciculations and K^+ release before paralysis
2. Histamine release
3. Cardiovascular effects
   a. Potential for bradycardia
   b. The more common response is tachycardia and hypertension caused by sympathetic stimulation
4. Hyperkalemia: caused by increased efflux of K^+ from endplate region of skeletal muscle
5. Some animals have a deficiency of plasma cholinesterase; in these animals, neuromuscular block may be prolonged
6. There is a genetic anomaly in which plasma cholinesterase is replaced by an atypical cholinesterase. Drug effects may be prolonged; differentiation is possible with dibucaine, which inhibits normal plasma cholinesterase 80% and atypical cholinesterase, only 20%.
7. Malignant hyperpyrexia: manifested by a severe, rapid rise in temperature; may be accompanied by significant muscle rigidity
   a. Usually occurs when using succinylcholine and halothane together
   b. Treat with 100% oxygen, rapid cooling, sodium bicarbonate to control acidosis, and dantrolene sodium (2 mg/kg of body weight)
   c. A genetic disease of pigs and humans

Nondepolarizing Blocking Drugs

I. Mechanism of action
   A. Competitive blocking drugs: compete with ACh for postsynaptic receptors, thereby reducing the depolarization caused by ACh

II. Indications
   A. Same as depolarizing drugs
   B. High-risk animals as part of a balanced anesthetic technique with narcotics, inhalants, or other analgesic drugs
   C. Ocular surgery
   D. Control of ventilation in anesthetized animals

III. Specific nondepolarizing drugs (see Table 10-2)
   A. Pancuronium (Pavulon)
      1. No histamine release or ganglionic block; no catecholamine release or inhibition
      2. Effects are enhanced by inhalant anesthetics

3. Major portion is excreted unchanged in urine
4. Tachycardia is occasionally seen after administration

B. Atracurium (Tracrium)
1. Developed as a rapid-onset and duration-competitive NMBD; can be administered by infusion
2. pH and temperature-dependent degradation (Hofmann elimination: a rapid degradation process that occurs in the plasma); a potential benefit is that biologically mediated metabolism and elimination by the liver and kidneys are not needed
   a. Hofmann elimination is a temperature- and plasma pH-dependent process
3. Some histamine release at high doses
4. Occasionally decreases heart rate and arterial blood pressure

C. Cisatracurium (Nimbex)
1. Isomer of atracurium producing less histamine release
2. Metabolism similar to atracurium (Hofmann elimination)
3. Cisatracurium's rate of degradation in vivo is highly influenced by body pH and temperature just as it is atracurium: an increase in body pH favors elimination; a decrease in temperature slows down the process
4. Slower onset of action than atracurium

D. Vecuronium (Norcuron)
1. Developed to produce a competitive NMBD with short onset and duration and to eliminate the tachycardia seen occasionally with pancuronium
2. Eliminated in bile (40%) and through the kidneys (15%)—a potential advantage in animals with compromised renal function

E. Rocuronium (Zemuron)
1. Derivative of vecuronium but less potent (1/6)
2. Faster onset than vecuronium
3. Sugammadex (Bridion) reverses neuromuscular blockade caused by rocuronium. It reverses neuromuscular blockade without relying on inhibition of acetylcholinesterase.

F. Mivacurium (Mivacron)
1. Slight histamine release
2. Long duration, slow clearance
3. Occasional decrease in arterial blood pressure

G. Pipecuronium (Arduan)
1. No histamine release

2. Low clearance eliminated by the kidney
3. Minimal cardiovascular effects

Additional Factors that May Influence Neuromuscular Blockade (Table 10-3)

I. Temperature
- A. Hyperthermia antagonizes competitive blockade but enhances and prolongs depolarizing blockade
- B. Hypothermia prolongs the duration of action of nondepolarizing NMBDs

II. Acid-base balance
- A. Respiratory acidosis augments nondepolarizing neuromuscular blockade
- B. Inadequate reversal of nondepolarizing drugs causes depressed ventilation and respiratory acidosis, which enhances the blockade

III. Fluid and electrolyte imbalance
- A. Hypokalemia and hypocalcemia potentiate nondepolarizing drugs
- B. Dehydration increases the plasma concentration of a normal dose of a nondepolarizing drug, augmenting its effect
- C. High Mg^{++} blood levels enhance both depolarizing and nondepolarizing NMBDs

IV. Other drugs
- A. The following antibiotics potentiate nondepolarizing drugs: neomycin, streptomycin, gentamicin, kanamycin, paromomycin, viomycin, polymyxin A and B, colistin, tetracycline, lincomycin, and clindamycin

TABLE 10-3 Factors Altering Intensity of Degree and Duration of Muscle Relaxation

Factor	Depolarizing Agent	Nondepolarizing Agent
Tranquilizers	↑	↑
Volatile anesthetic agents	↑	↑
Decreased body temperature	↑	↑
Hypotension (decreased cardiac output)	↓	↓
Increased age	↑	↑
Antibiotics	↑	↑
Organophosphates	↑	—

↑, Increase; ↓, decrease; —, no effect.

Anticholinesterase Drugs

I. Reversal of non-depolarizing neuromuscular block
- A. Anticholinesterase drugs such as edrophonium, neostigmine, physostigmine, and pyridostigmine can be used with or without anticholinergic drugs
  1. Atropine or glycopyrrolate can be used to block the undesirable muscarinic effects of anticholinesterase drugs; muscarinic effects include bradycardia and increased bronchial and salivary secretions, and increased intestinal motility
  2. This regimen is ineffective against depolarization block; in fact, it exacerbates the block because of additional depolarization by excess ACh
  3. This regimen may be effective when a depolarizing, blocking drug is producing a phase II block
- B. Reverse with 0.02 to 0.04 mg/kg neostigmine preceded by 0.01 to 0.02 mg/kg atropine (average dose) or glycopyrrolate (0.005 to 0.01); do not repeat the neostigmine dose more than three times
- C. Edrophonium dose is 0.5 mg/kg intravenously (IV); it may be repeated up to five times
  1. Complete reversal takes 5 to 45 minutes
- D. Sugammadex reverses neuromuscular blockade caused by rocuronium. The main advantage of sugammadex is reversal of neuromuscular blockade without relying on inhibition of acetylcholinesterase.

Centrally Acting Skeletal Muscle Relaxants

I. There are dozens of centrally acting muscle relaxants that are used to alleviate musculoskeletal spasms and pain in human and veterinary medicine. Only a few benzodiazepines (e.g., diazepam, midazolam, zolazepam) and guaifenesin are regularly administered to animals (see Chapters 3 and 8)
- A. Centrally acting muscle relaxants produce muscle relaxation, ataxia, anxiolysis, and convulsion antagonism

II. Guaifenesin
- A. The mechanism of action is poorly understood but is linked to depression of transmission through spinal polysynaptic pathways, which normally maintain SM tone
- B. No effect on cerebral arousal
  1. Mild sedation; poor "anesthetic"
  2. Variable, mild analgesia

C. Clinical use: significantly reduces the dose of induction drug (ketamine, propofol) required to produce recumbency and immobilization
D. Doses and route of administration
1. 50 to 100 mg/kg or to ataxic effect by IV infusion; 100 mg/kg for recumbency by IV infusion
2. Typically administered as a 5% solution

II. Benzodiazepines (diazepam, midazolam) (see Chapter 3)
A. Mechanism of skeletal muscle relaxant activity is probably related to the ability to activate benzodiazepine receptors, activate chloride channels, and potentiate gamma-aminobutyric acid (GABA), a central nervous system inhibitory neurotransmitter
1. Benzodiazepines enhance the effect of the neurotransmitter GABA by binding to the benzodiazepine site on the GABA A receptor leading to central nervous system depression
a. Either diazepam or midazolam can be administered immediately before ketamine or propofol to enhance the quality of induction to anesthesia

11 Equipment for Tracheal Intubation and Securing the Airway

"Breathing is the essence of life. Breathe deeply, live fully."
GABRIELLA GODDARD

OVERVIEW

Orotracheal intubation is performed to facilitate ventilation and deliver inhalant anesthetics and oxygen and occasionally other gases (e.g., carbon dioxide, helium). Proper placement of an endotracheal tube ensures the most efficient delivery of volatilized gases and oxygen and helps prevent aspiration of respiratory secretions, saliva, or regurgitated stomach contents. Oxygen and inhalant anesthetics can also be delivered via face mask or laryngeal mask airway (LMA). Most domestic species are relatively easy to orally intubate. Occasionally, alternative methods of gas delivery such as intubation via pharyngotomy or tracheotomy or using a facemask are employed.

Intubation Purposes

I. Ensure a patent airway
II. Prevent aspiration
III. Minimize airway resistance
IV. Facilitate administration of oxygen and inhalant anesthetics
V. Facilitate assisted or controlled ventilation
VI. Limit operator exposure to waste anesthetic gases

Endotracheal Tubes (Fig. 11-1)

I. General considerations
  A. Most are made of polyvinyl chloride (PVC), silicone, or rubber
  B. Generally the PVC tubes have a curvature to facilitate placement. Silicone tubes lack a curvature and are less stiff than PVC or rubber.
  C. PVC tubes are available in several sizes: 2-10 mm internal diameter (ID). Size 2 is uncuffed. PVC cannot be steam autoclaved.
  D. Larger sizes are available for larger animals
    1. Silicone tubes can be steam autoclaved

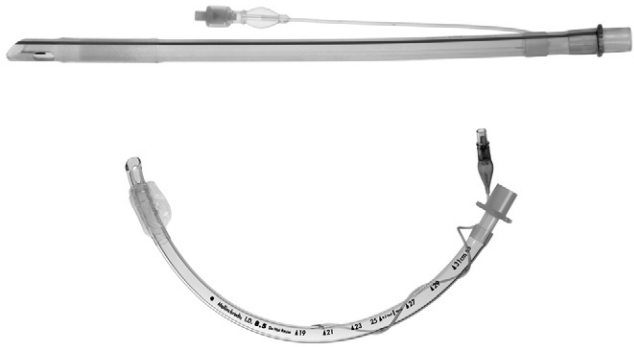


FIG. 11-1. Silicone (flexible; top) and PVC (rigid; bottom) endotracheal tubes.

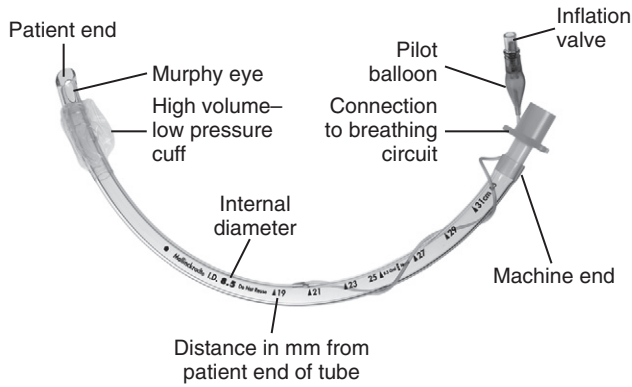


FIG. 11-2. Components of a PVC endotracheal tube. Note the internal diameter and distance measurements.

II. Components (Fig. 11-2)

A. Sizes: endotracheal tubes are sized by ID (mm); outside diameter (OD, mm, or French [3 × OD]). OD is typically 3 to 4 mm larger than ID, depending on the overall tube size.

B. Cuffed endotracheal tubes (Fig. 11-3)

1. High volume-low pressure: cuff volume is relatively large
   a. Cylindrical shape when inflated; pressure is distributed along the entire length of cuff
2. Low volume-high pressure: cuff is more ovoid when inflated
   a. Relatively greater pressure at contact point with the trachea

C. Uncuffed endotracheal tubes

1. Specialized tubes with cuffless systems that replace the cuff (Fig. 11-4)

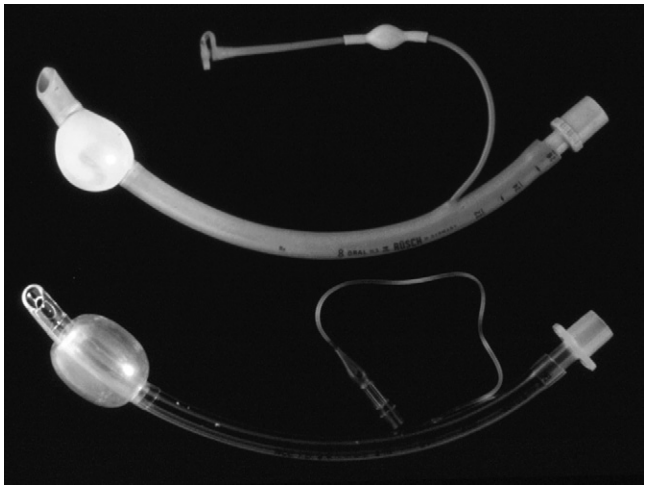


FIG. 11-3. Examples of endotracheal tubes with high pressure-low volume (top) and low pressure-high volume (bottom) cuffs. Either type of cuff is suitable for relatively short-term intubation. Note that the high pressure-low volume cuff (top) can produce eccentric pressure against the tracheal wall.



FIG. 11-4. Silicone endotracheal tubes with flexible fins instead of a cuff. Note that a stylet is partially withdrawn from lumen of the tube. The stylet stiffens the tube and facilitates manipulation of the tube into the larynx during intubation. The stylet is withdrawn once the tube is inserted.

D. Spiral embedded endotracheal tubes: metal or nylon spiral winding within the wall of the tube
   1. Resist kinking and occlusion of lumen when bent at extreme angles
   2. Disadvantage: can be permanently compressed if bitten
E. Laser shielded endotracheal tubes: useful during laser surgery of the airway

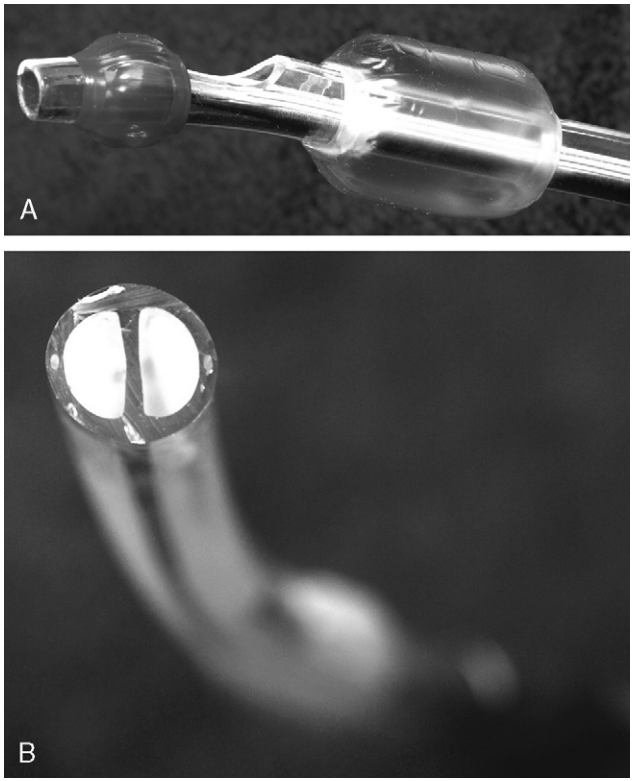


FIG. 11-5. Double lumen tubes are used for selective lung ventilation. (Photographs by Michael Chen, M. D. IN Cote CJ, et al: *A Practice of Anesthesia for Infants and Children*, ed 4, Philadelphia: Saunders, 2009.)

1. Shielded with aluminum, copper, or flexible stainless steel
2. Cuff is wrapped with cottonoid that is moistened to resist burn-through

F. Tubes for one lung ventilation:
1. Double lumen tubes (Fig. 11-5)
2. Right or left sided so that either right or left lumen is longer and can be inserted into the appropriate mainstem bronchus, isolating it from the other lung. The other lumen and cuff reside in the mainstem bronchus.
3. Useful for thoracoscopic surgery
4. Using an appropriate adapter, one or both lungs can be ventilated together or independently. One lung can be isolated while the other is ventilated.
   a. Proper placement is facilitated by bronchoscopy



FIG. 11-6. Facemasks are available in various sizes. Choose a mask size that allows the animal's muzzle to fill the volume of the mask. These masks have a flattened side to facilitate use during recumbency.

Endotracheal Tube Alternatives

I. Face masks (Fig. 11-6)
- A. Various sizes of masks are commercially available for small animals
  1. Mask should ideally provide a seal to atmosphere with minimal dead space between animal's muzzle and the mask
  2. Masks can be fashioned from large plastic bottles for use in large animals

II. LMA (Fig. 11-7, *A*, and *B*)
- A. A silicone tube attached to an inflatable mask: the machine end of the tube connects to the breathing circuit and the mask end forms a circumferential seal around the larynx
- B. LMA mask "self positions" itself around the glottis when blindly inserted
  1. Cuff inflated to develop a seal
  2. Inserted blindly or with aid of a laryngoscope

Intubation Aids

I. Light source:
- A. Flashlight or penlight
- B. Laryngoscope (Fig. 11-8): provides a light source at the end of a flat or curved blade to aid in illuminating the larynx and manipulating tissues of the oral cavity
  1. Multiple styles and sizes are available
  2. A Miller blade (size 4 and size 1) or other comparably sized straight blade for dogs and cats
  3. Elongated blades up to 40 cm are available for use in large-animal species

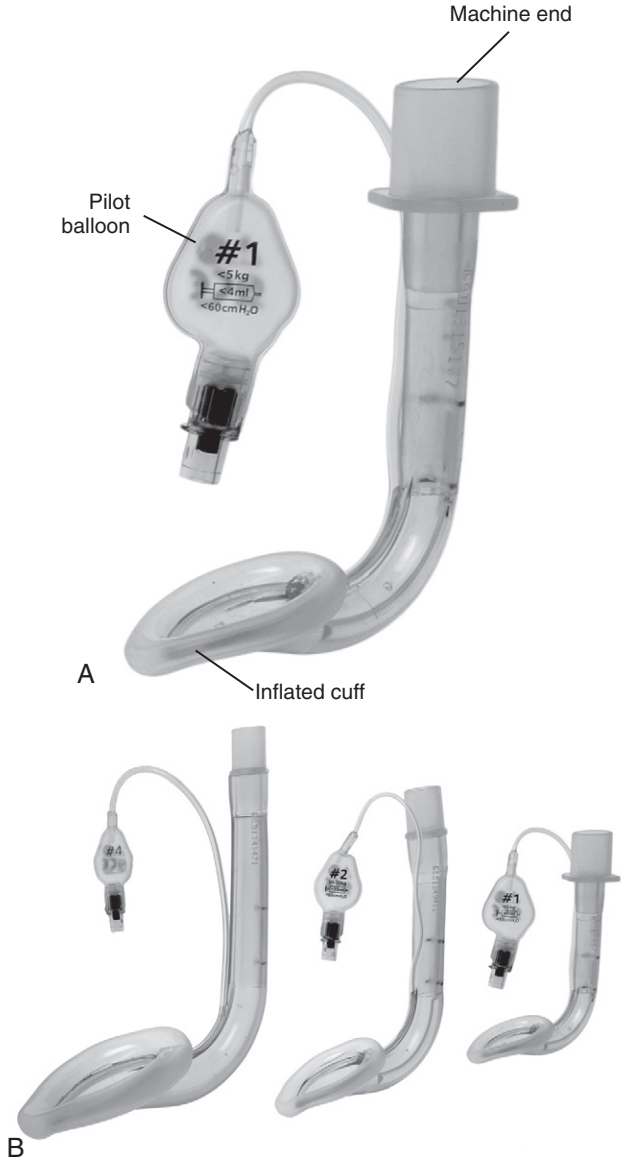


FIG. 11-7. Laryngeal mask airways (LMAs). **A,** The cuffed end of the LMA is inserted into the posterior pharynx and the cuff inflated to provide a seal between the device and the larynx. LMAs do not reliably seal the airway from fluid. **B,** A variety of sizes is available.



FIG. 11-8. Laryngoscopes with light sources can be used to facilitate orotracheal visualization and placement of endotracheal tubes. A large-animal laryngoscope (*top*) and a Miller size 4 laryngoscope (*bottom*) suitable for medium- to large-sized dogs and small ruminants.



FIG. 11-9. An endotracheal tube cuff pressure manometer for determining cuff-inflation pressure.

II. Pressure manometer (Fig. 11-9)
- A. Can be attached to inflation valve of endotracheal tube
- B. Indicates endotracheal cuff pressure
  1. High volume-low pressure maximum inflation up to 25 cm H_2O
  2. Low volume-high pressure inflation may reach 80 cm H_2O
  3. Add just enough air into the cuff to seal the airway so that the lung can be inflated to a positive pressure of 20 to 25 cm H_2O

Endotracheal Tube Complications

I. An oversized endotracheal tube can cause tracheal and laryngeal edema and inflammation predisposing to upper airway obstruction once the tube is removed

II. An undersized endotracheal tube causes increased resistance to breathing leading to increased work of breathing (increased respiratory effort) which could lead to poor gas exchange or the misinterpretation of anesthetic depth (inadequate depth) leading to an inappropriate administration of additional anesthetic drug

III. Insertion of the endotracheal tube too far into the trachea can result in endobronchial intubation, poor gas exchange, and difficulty in maintaining an appropriate depth of anesthesia

IV. Inadequate insertion of the endotracheal tube can result in difficulty maintaining an appropriate depth of anesthesia and laryngeal trauma

V. Insertion of the tracheal tube in the esophagus can result in an inability to maintain anesthesia and respiratory failure

A. The end-tidal carbon dioxide will be 0 when the tube is in the esophagus

VI. Kinking or occlusion (blood, mucus) will lead to poor gas exchange or inappropriate administration of additional anesthetic drug (misinterpretation of anesthetic depth)

VII. Inadequate inflation of the endotracheal tube cuff can lead to poor gas exchange, inability to maintain an appropriate depth of anesthesia due to leaks or inappropriate administration of additional anesthetic drug

VIII. Overinflation of the endotracheal tube cuff can result in tracheal wall inflammation and postanesthetic coughing of several days' duration

A. Endotracheal tubes should be cleaned inside and out with mild detergents, thoroughly rinsed, and air dried

12 Anesthetic Machines and Breathing Systems

"Give the tools to him that can handle them."
NAPOLEON BONAPARTE

OVERVIEW

A variety of equipment is used to deliver inhalant anesthetic drugs. Volatilizing inhalant anesthetics from their liquid form and safely delivering precise concentrations to the animal while minimizing environmental pollution requires the use of relatively sophisticated, expensive, and, at times, cumbersome devices. Regardless of their apparent complexity, most inhalant anesthetic drug-delivery systems use similar, simple designs to deliver oxygen (O_2) and anesthetic concentrations and remove carbon dioxide (CO_2) and waste gases.

General Considerations

Most anesthetic delivery systems contain the same components. They reduce the pressure of stored O_2 and nitrous oxide (N_2O) and precisely mix these gases with volatilized inhalant anesthetic drugs for delivery into a breathing circuit.

Anesthetic Equipment

I. Compressed gases: O_2, N_2O, and other select gases come in color-coded cylinders of varying size (Tables 12-1 and 12-2). O_2 is used as the carrier gas for delivering inhalant anesthetics in most anesthetic circuits
   A. Cylinders should be handled carefully
      1. Never leave an unsupported or unsecured cylinder sitting upright
         a. Store E cylinders in a rack
         b. Secure H cylinders anchored to a wall or a transport cart with a chain
      2. A cylinder may explode if dropped because it is under high pressure
      3. Open cylinder valves slowly and completely

TABLE 12-1 Compressed Gases

CYLINDER SPECIFICATION (liters, STP)

Agent	E (8.8 cm × 66 cm)	G (17.6 cm × 121 cm)	H (19.8 cm × 121 cm)	Filling Pressure (psi)
Oxygen	655	5290	6910	2200
Nitrous oxide	1590	12,110	14,520	750
Carbon dioxide	1590	4160		800
Helium	500	4350	5930	1650

Psi, Pounds per square inch; STP, standard temperature and pressure.

TABLE 12-2 United States and IOS (International Organization For Standardization) Gas Color Codes

Gas or Function	United States	IOS
Oxygen	Green	White
Nitrous oxide	Light blue	Light blue
Medical air	Yellow	Black and white
Suction	White	Yellow
Nitrogen	Black	Black
Carbon dioxide	Gray	Gray
Helium	Brown	Brown

4. Crack the cylinder valve (open and shut quickly) before attaching it to the machine to remove dust from the connecting port (dirt or dust plus rapid compression at the connecting port can cause a fire)
5. Install a new gasket when connecting each full cylinder to the connecting port

B. Most veterinary and human anesthetic machines have a hanger yoke for attaching one or more E cylinders; hanger yokes and E cylinders are keyed (coded) with a pin index safety system to prevent inadvertent connection of the wrong cylinder to the wrong gas yoke on the anesthetic machine (Fig. 12-1)

C. Centralized O_2 sources usually use G or H cylinders
   1. H cylinders require an individualized pressure regulator (thread size and connection are coded for different types of gas)

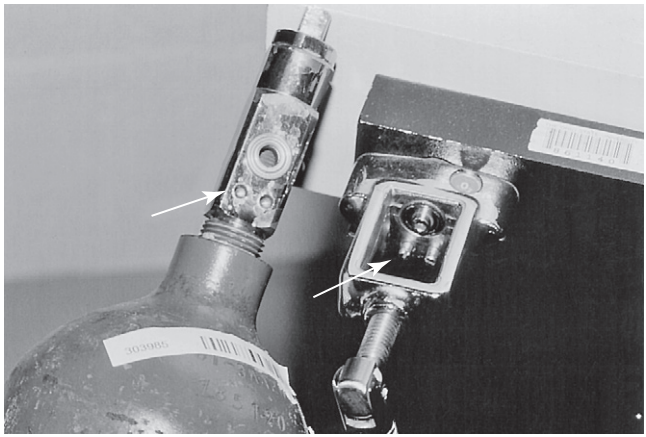


FIG. 12-1. The pin index system ensures that the appropriate tank is selected and properly secured to the anesthetic machine.

2. These cylinders are attached to the machine by a length of high-pressure hose connected to the Diameter Index and Safety System fitting of the machine
3. In some older systems, the high-pressure hose is connected to a special yoke-block connector that attaches to the pin index system in the hanger yoke

D. O_2 and N_2O
1. O_2 is present within the cylinder only as a gas, and its pressure is proportional to gas volume
2. N_2O is present within the cylinder as a liquid and a gas
   a. Pressure within the tank remains constant at 750 pounds per square inch (psi) until all the liquid is gone; the pressure then falls

E. Oxygen generators can be installed for central gas supply; they extract O_2 from the environment (air: 20% O_2) to produce 90% to 95% O_2
1. Various sized oxygen generators are available depending on the volume of gas required

II. Hanger yoke site for E cylinder (see Fig. 12-1)

A. Pin index system configuration avoids improper cylinder connection

B. A brass filter prevents particulate contamination of the anesthetic machine's gas lines

C. Pressure gauges are located on the anesthetic machine or attached directly to the cylinder display cylinder pressure

D. One-way (check) valves prevent transfilling of adjacent cylinders or loss of O_2 from the cylinder into the pipeline supply

III. Pressure-reducing valves (pressure regulators) are built into most anesthetic machines or can be attached directly to the cylinder
- A. Pressure-reducing valves reduce the pressure within the cylinder to a constant outlet pressure of about 50 psi
- B. Provide constant pressure to the flowmeter
- C. Allow a wide range of gas flow (L/min; mL/min) settings
- D. Ensure that the flowmeter does not have to operate at high pressures
- E. Hospital supply cylinders (G and H) require individualized regulators

IV. O_2 "fail-safe" system
- A. Many but not all anesthetic machines incorporate an O_2 "fail-safe" system: if the O_2 supply is interrupted, N_2O and any other gas flow is automatically interrupted
- B. An audible O_2 supply failure alarm also activates on some machines
- C. Not all machines are so equipped, which means if the O_2 supply is interrupted, N_2O may be delivered without O_2

V. Flowmeters
- A. A flowmeter controls the rate at which a specific gas (e.g., O_2) is delivered (milliliter per minute, liter per minute). The most common gas flowmeter is the rotameter.
  1. Flowmeters contain a ball or bobbin that rises within a tapered glass tube to a height proportional to the flow of gas through the tube. The gas flow rate is read at the widest diameter of the ball or bobbin.
- B. Ideally, the O_2 flowmeter should be the last in a series of flowmeters (a hypoxic gas mixture is less likely to develop if a flowmeter tube is cracked)
- C. Avoid excessive torque (twisting) when closing flowmeters, because the knobs can come to be out of adjustment or be twisted off
- D. Flowmeter tubes are gas-specific; an N_2O flow tube cannot be substituted for an O_2 tube
- E. Individual gas flows are combined downstream from the flowmeters; from there, gases move to an out-of-circuit vaporizer or directly to the anesthetic circuit
- F. Some machines are equipped with two O_2 flowmeters
  1. They can be connected in series or in parallel

a. If in parallel, they can be individually adjusted and the flow from both is additive
b. One flowmeter is used for low flows (up to 1 L/min)
c. The other is used for flows greater than 1 L/min

2. If in series, one knob controls flows through both flowmeters

VI. O_2 flush valve

A. Diverts O_2 past the vaporizer and delivers O_2 directly to the common gas outlet or anesthetic circle
B. Delivers O_2 rapidly to the circle at 35 to 75 L/min
C. Dilutes the anesthetic gases in the system

VII. Common gas outlet: the point-of-gas-exit from the machine for O_2, N_2O, and vaporized (out-of-circuit) anesthetic gas. It has a 15-mm connector.

VIII. Anesthetic vaporizers

A. Vaporizers are designed to volatilize liquid inhalant anesthetic drugs and to deliver clinically useful concentrations of anesthetic vapor
B. Anesthetic machine vaporizers are located near the flowmeters and can be either out (vaporizer out of the circuit [VOC]) or in (vaporizer in the circuit [VIC]) the anesthetic breathing circuit

1. Precision VOC vaporizers deliver precise anesthetic concentrations (%) of anesthetic vapor that are relatively independent of temperature and fresh gas flow rate; the manufacturer specifies limits of temperature and flow
2. Gas flow within the vaporizer is split between a bypass and vaporization chamber
   a. The splitting ratio between these two chambers depends on the saturated vapor pressure of the anesthetic and the desired output (%) of anesthetic vapor
3. Precision VOCs are agent-specific
   a. Isoflurane vaporizers
      (1) Ohio Calibrated Vaporizer for Isoflurane (Ohmeda)
      (2) Vapor 19.1 (Dräger)
      (3) Isotec (Ohmeda)
   b. Sevoflurane vaporizers
      (1) Sevotec 3, Sevotec (Tec 5) (Ohmeda)
      (2) Sevomatic (A.M. Bickford)
      (3) Sigma Delta (InterMed Penlon)
   c. Desflurane vaporizer

(1) Tec 6 vaporizer (Ohmeda): electronically heated vaporizer; unique construction because of the physical-chemical properties of desflurane

d. Maintenance
   (1) Vaporizers should be sent to the manufacturer for cleaning and recalibration
   (2) They should be serviced whenever the dial setting (%) does not match clinical perception of anesthetic depth

4. VICs (also called draw-over vaporizers): the concentration delivered is temperature and flow dependent
   a. Draw-over vaporizers are not agent-specific
   b. Output depends on the following:
      (1) The inhalant anesthetic's volatility: less volatile agents (e.g., ether) require a wick; current inhalant anesthetic drugs (isoflurane, sevoflurane) need no wick
      (2) Temperature: vapor pressure and therefore vaporizer output increases or decreases with ambient temperature
      (3) Overdose can occur at high ambient temperatures
      (4) Animals may be difficult to keep anesthetized at low ambient temperatures
   c. Flow-through vaporizer
      (1) Controlled by animal's minute ventilation; increases in depth and rate of ventilation (spontaneous or assisted) increase the vaporizer output
   d. Vaporizer construction
      (1) Wick versus no wick; adjustable sleeves; distance between the surface of the liquid and the gas flow
   e. Location of vaporizer in the breathing circuit
      (1) The vaporizer should be mounted on the inspiratory side to reduce the condensation of water in the vaporizer
   f. Calibration marks on top of the vaporizer do not indicate the percentage output of VIC vaporizers
   g. Types
      (1) Ohio No. 8 Vaporizer (Pitman-Moore); wick must be removed when using with isoflurane or sevoflurane

(2) Stephens (Henry Schein); wick must be removed when using with isoflurane or sevoflurane

h. Maintenance: wick should be allowed to dry weekly to rid system of excess water vapor

C. General comments

1. Vaporizers should be filled with anesthetic in a well-ventilated area at the beginning or end of the day to minimize exposure of personnel to vapor
2. Vaporizers must be in the off position when filling or draining
3. Special filling devices are available to minimize spills and escape of vapors into the environment
4. Vaporizers should not be tilted or laid on their sides unless completely drained; dangerously high concentrations can result during subsequent use

Anesthetic Breathing Systems

I. Purpose

A. The safe delivery of inhalant anesthetics and O_2

B. Removal of CO_2 and excess anesthetic gases

1. Dilution (e.g., T piece [Mapleson] systems)
2. CO_2 absorbents (Sodasorb, Amsorb)

II. Types of systems

A. Open drop or cone system (Fig. 12-2)

1. Features
   a. No reservoir
   b. Minimal or no rebreathing of expired gases
   c. CO_2 removal by dilution
2. Advantages
   a. Low cost of equipment
   b. Minimal or no rebreathing of expired gases
   c. Minimal resistance to breathing (especially open drop)
3. Disadvantages
   a. Wasteful because so much anesthetic is vaporized
   b. Difficult to control anesthetic concentration delivery
   c. No method of assisting ventilation
   d. Difficult or impossible to scavenge waste gas
   e. Vaporization of anesthetic depends on room temperature (open drop and cone)

B. Nonrebreathing valveless systems (Mapleson classification) rely on relatively high, fresh gas flow rates (Table 12-3) to remove CO_2. The following classifications are based on the

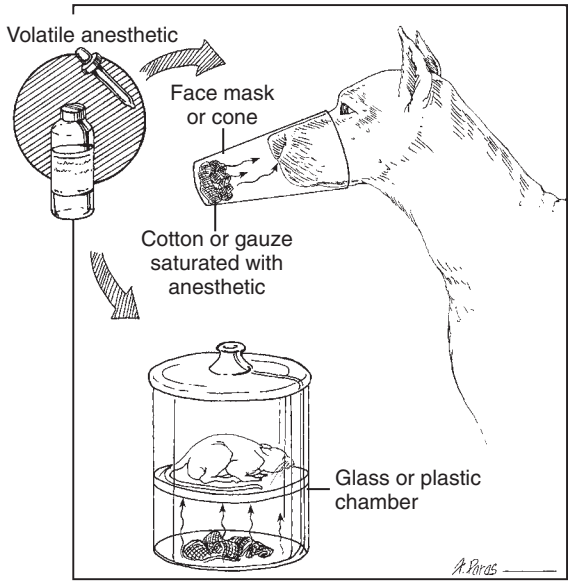


FIG. 12-2. Open system: the animal is exposed to or breathes room air. Gauze or cotton is saturated with inhalant anesthetic and placed in a cone or chamber from which the animal breathes.

TABLE 12-3 Recommended Oxygen Flow Rates for Anesthetic Systems

NONREBREATHING SYSTEMS	
Mapleson systems*	
Magill system	100 mL/kg/min
Lack system	150 mL/kg/min
Ayre's T piece	150 mL/kg/min
Bain circuit	150 mL/kg/min
Insufflation	200-300 mL/kg/min
REBREATHING OR CIRCLE SYSTEMS	
Closed	3-5 mL/kg/min†
Semi-closed low flow	5-10 mL/kg/min‡
Semi-closed high flow	20-30 mL/kg/min‡

*Do not use during controlled or assisted ventilation.
†Do not use nitrous oxide in a closed circle unless in-circuit oxygen analyzer is used.
‡If using nitrous oxide, add to the oxygen flow.

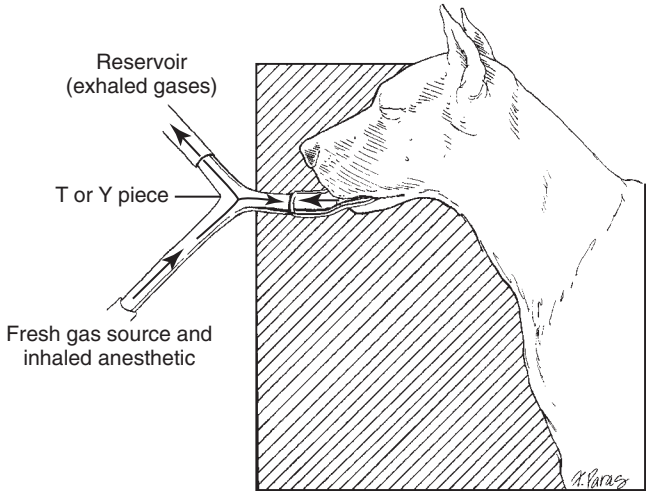


FIG. 12-3. Mapleson F (Ayres T piece). Provides a low-resistance method of delivering inhalant anesthetic and oxygen. High fresh gas flow rates are used to minimize or eliminate rebreathing of exhaled gas.

location of fresh gas inlet and opening (or valve) for exit of exhaled gas. The relative location of the fresh gas inlet and the valve opening determine the efficiency of the circuit.

1. Types
   a. Rees modification of Ayre's T piece (see Fig. 12-3) (Mapleson F): fresh gas enters near the patient and exits from the reservoir bag
   b. Bain circuit (modified Mapleson D): fresh gas enters circuit near the bag, but in the coaxial (tube in a tube) design, it delivers anesthetic through an inner tube to a point near the patient; exhaled gas passes around the fresh gas line to exit near the bag (Figs. 12-4 and 12-5)
   c. Lack system (modified Mapleson A): fresh gas is delivered via a large-bore corrugated tube surrounding a smaller inner tube that carries exhaled gas to a pressure relief valve at the distal end of the circuit (opposite of the Bain; see Fig. 12-4)
      (1) These three systems are relatively efficient during both spontaneous and controlled ventilation. Fresh gas flow rate during spontaneous and controlled ventilation should be set to equal 150 mL/kg of body weight/min.

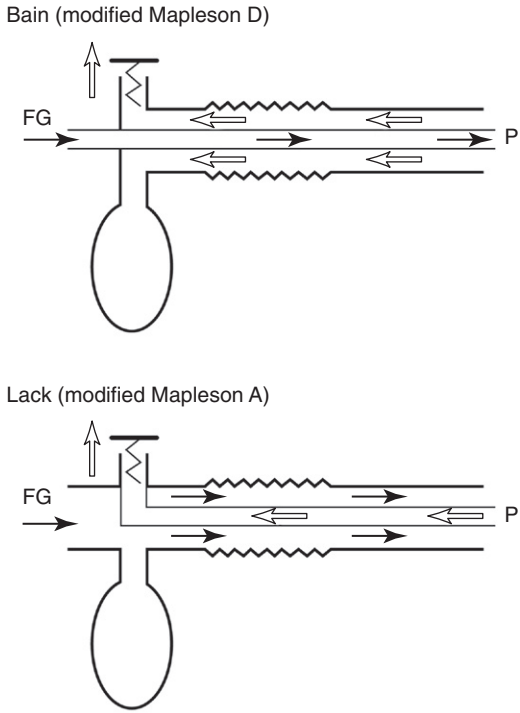


FIG. 12-4. Examples of nonrebreathing systems (Bain, Lack). Note the difference in the direction fresh gas (*FG*) flow. *P*, patient (animal).

   d. Magill system (Fig. 12-6) (Mapleson A): fresh gas enters near bag and exhaled gas exits through a pressure relief valve located near the patient
      (1) Very efficient during spontaneous ventilation (fresh gas flow needs to match minute alveolar ventilation)
      (2) Very inefficient during controlled ventilation (fresh gas flow = 3 to 5 × minute ventilation)
2. Advantages and disadvantages of all nonrebreathing circuits
   a. Advantages: low equipment dead space, low resistance to breathing
   b. Disadvantages: relatively wasteful of O_2 and volatile anesthetic. High gas (O_2) flow rates contribute to decreases in the animal's temperature.

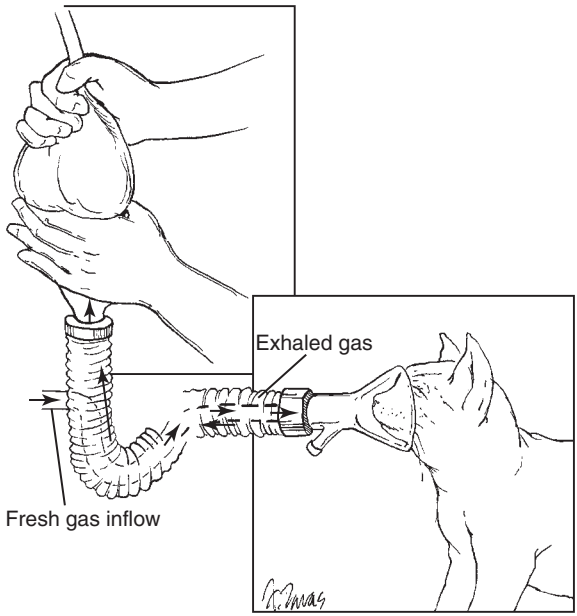


FIG. 12-5. Modified Mapleson D Bain circuit. Functions similarly to Ayres T piece system. Fresh gas is delivered to the orotracheal tube or face mask attachment to minimize dead space. In this drawing, dead space is due to the face mask.

C. Rebreathing anesthetic circuits allow rebreathing of exhaled gases minus CO_2; amount of rebreathing depends on the fresh gas flow rate
   1. Circle system (Figs. 12-7 and 12-8)
      a. Components
         (1) Pressure relief ("pop-off") valve
            (a) Allows the release of excess pressure from the system; the volume of gas in excess of the animal's minute O_2 consumption is vented from the system
            (b) Fitted with spring-loaded or variable orifice valves; when in the fully open position, modern valves usually "pop off" or open when pressure exceeds 0.5 to 1 cm H_2O; as valve is tightened down, more pressure is required to open valve
            (c) Fitted with orifice or hood for scavenging waste gas

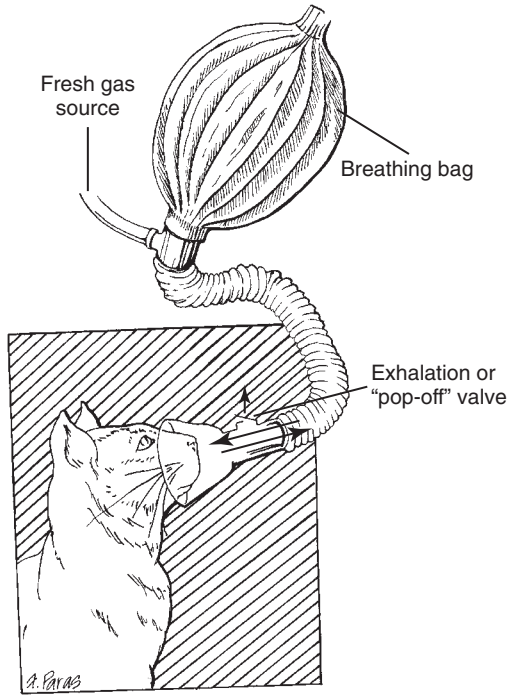


FIG. 12-6. Mapleson A Magill system. Low fresh gas flow rates can be used during spontaneous ventilation because a pressure relief ("pop-off") valve is placed near the animal and exhausts alveolar gas.

(d) Devices are available that allow rapid "push-button" closing and opening of the valve

2. Carbon dioxide absorbent canister (Table 12-4)
   a. Contains a material that chemically removes CO_2 from the expired gases
   b. Capacity should be at least one to two times tidal volume (V_T = 10 mL/kg)
      (1) Most small-animal machine canisters have a capacity of 1.5 liters; most large-animal canisters have a capacity of 5 liters
   c. Active ingredients are various proportions of K^+, Ca^{++}, and Na^+ hydroxide. These hydroxides react with exhaled CO_2 and water to form carbonate; heat is liberated, pH decreases
   d. Use 4- to 8-mesh, granule size

TABLE 12-4 Chemical Composition of Some Carbon Dioxide Absorbents

CO_2 Absorbent	$Ca(OH)_2$ (%)	KOH (%)	Na(OH) (%)	$CaCl_2$ (%)	CaSO4 (%)	H_2O (%)	Silica (%)	Polyvinylpyrrolidone (%)
Sodium hydroxide lime (classic Sodasorb)	80-81	2.0-6.0	1.3-3.0	—	—	14-18	0.1	—
Sodium hydroxide lime (Sodasorb LF)	81.5	0.003-0.005	2.0-2.6	—	—	14-18	0.1	—
Calcium hydroxide lime (Amsorb plus)	75-83	—	—	0.7	0.7	14.5	—	0.7

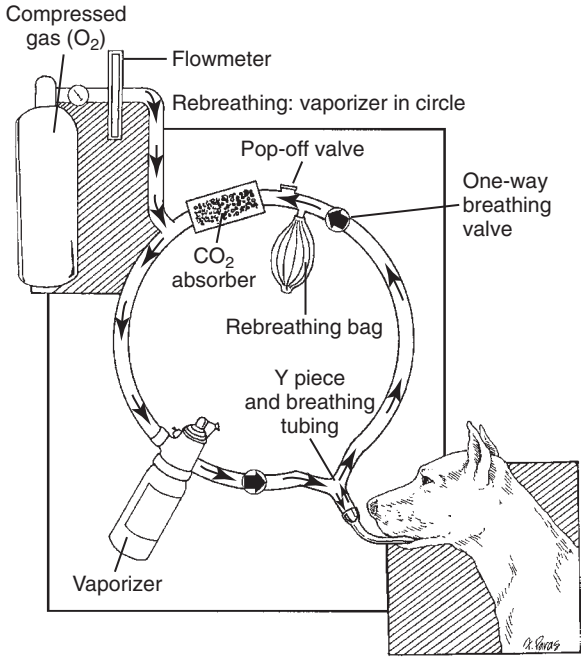


FIG. 12-7. Anesthetic circle system with the vaporizer in-circle (VIC). This type of anesthetic circuit is frequently used when low fresh gas flow rates are delivered. Several portable anesthetic (Komesaroff, Stephens) systems are designed to deliver low fresh gas flow rates.

e. CO_2 absorbent has a pH color-change indicator (usually ethyl violet) that turns blue on consumption; the indicator may revert to its original color when allowed to rest; absorbent should be changed after 6 to 8 hours of use, depending on fresh gas flow rates and size of the animals anesthetized since the last change of contents (Fig. 12-9)
f. Absorbent becomes brittle, dusty, and clumps together when no longer useful
   (1) Desiccated absorbent can liberate various toxins (e.g., compound A, carbon monoxide, formaldehyde, methanol) (see Chapter 9). Certain absorbents (Sodasorb LF and Amsorb Plus) minimize these reactions.
g. Change absorbent at appropriate intervals to avoid accumulation of compound A from sevoflurane and

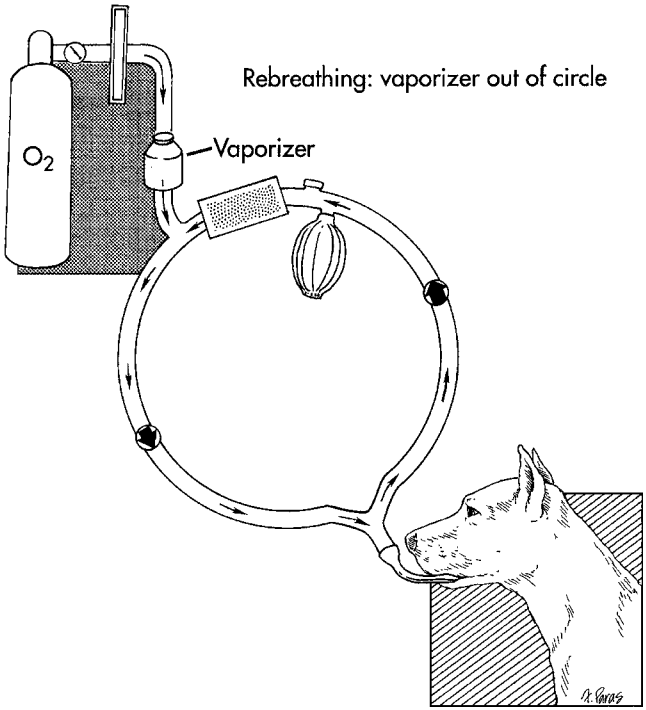


FIG. 12-8. Vaporizer out of circuit (VOC) anesthetic circuit. Note the location of the vaporizer is outside the circle, which contains the CO_2 absorbent, one-way breathing valves, and rebreathing bag.

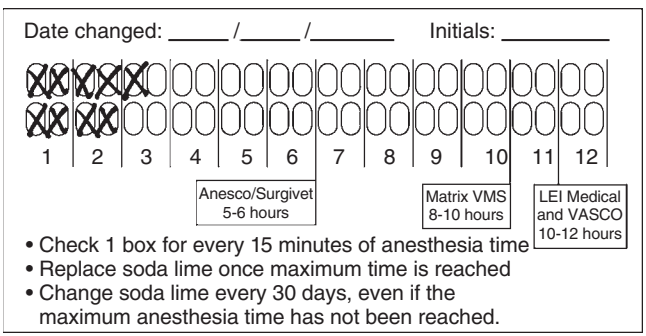


FIG. 12-9. The total time that the carbon dioxide (CO_2) absorbent has been used should be monitored to ensure CO_2 removal from the anesthetic circuit. Larger animals produce more total CO_2. The CO_2 absorbent material should be replaced if capnometry indicates a consistent increase in inspired CO_2 concentration.

accumulation of carbon monoxide from desflurane, isoflurane, sevoflurane, and halothane
(1) Be certain O_2 flow is turned off when not in use to avoid absorbent desiccation and associated increase in breakdown products

3. Two unidirectional flow valves prevent exhaled gas from being rebreathed before it passes through the absorbent canister
4. Vaporizer (VIC or VOC; see Figs. 12-7 and 12-8)
5. Rebreathing bag (reservoir bag) is available in the following sizes:
   a. 0.5 L: for animals weighing less than 3 to 5 kg
   b. 1 L: for animals less than 5 to 7 kg
   c. 2 L: for animals between 7 and 15 kg
   d. 3 L: for animals between 15 and 50 kg
   e. 5 L: for animals between 50 kg and 150 kg
   f. 35 L (large-animal system): for animals more than 150 kg
6. Pressure manometer
   a. Monitors pressure within breathing system
   b. Typically calibrated from -30 to +50 cm H_2O
   c. Pressure within circle increases when bag is squeezed, particularly when the "pressure relief" valve is closed
   d. Useful to determine delivered airway pressure during manual or mechanical ventilation
7. Corrugated breathing tubes and Y piece
   a. Generally 1 meter long and 22 mm in diameter for small animals
   b. Longer tubes are used when machines cannot be located near the patient's head
   c. Shorter tubes with small diameter (13 mm) are used for animals weighing less than 5 kg
   d. Large animal tubes are 50 mm in diameter
   e. Advantages of circle system:
      (1) Relatively low gas flow rates can be used (economical and minimize pollution)
      (2) CO_2-absorbent canister is located away from patient, as opposed to to-and-fro system
      (3) Ventilation is readily observed and controlled by reservoir bag
      (4) Minimal heat loss and airway drying
      (5) Absence of abrupt fluctuations in anesthetic depth

f. Disadvantages:
   (1) System is bulky
   (2) Parts may be inappropriately rearranged or may malfunction
   (3) Resistance to gas flow is greater than with Mapleson systems; conventional circle systems should not be used in animals weighing less than 3 kg
   (4) Some components are difficult to clean
   (5) Cross-infection of animals is possible but rare; bag and hoses should be disinfected after each use
   (6) Concentration within system typically does not match the vaporizer setting
   (7) System concentration changes slowly when vaporizer setting is adjusted, especially with relatively low fresh gas flow rates

8. Fresh gas flow rates for rebreathing systems (Box 12-1)
   a. Minimum O_2 flow rate equals minute O_2 consumption

BOX 12-1

Generic Anesthesia Machine and Breathing Circuit Checklist

I. Inspect machine
   A. Turn off vaporizers, fill vaporizers, tighten filler caps
   B. Fill CO_2 canister with absorbent
   C. Confirm proper function of unidirectional valves in circle—with surgical mask inhale and exhale through Y piece*
II. Confirm oxygen supply and fail safe
   A. Check cylinder pressure
   B. Turn on N_2O cylinder and flowmeter; turn O_2 cylinder off; N_2O float should drop to zero; reopen O_2 cylinder*
III. Verify proper flowmeter functions—bobbin or float should move freely throughout length of tube*
IV. Check breathing circuit
   A. Proper, tight connections
   B. Occlude Y piece, close pressure relief valve, pressurize circuit to 30 cm H_2O; check for leaks; open pressure relief valve and confirm release of pressure
V. Check waste gas scavenging system (if attached)*
   A. Confirm that scavenging system is connected to pressure relief valve
   B. Turn on vacuum pump or verify patency of passive system
VI. Check ventilator function
   A. Verify connection to breathing circuit
   B. Check for leaks according to manufacturer

*Need only be performed daily

(1) About 2 to 3 mL/kg/min
(2) Because the volume of fresh gas delivered equals patient uptake, the volume of the system will not change; the pressure relief valve can remain closed, but does not have to
(3) Advantages of closed system
  (a) Minimal pollution
  (b) Economical
  (c) Breathing system warmth and humidity maximized
(4) Disadvantages
  (a) Difficult to rapidly change concentration: closed system flow rate cannot be used for the first 10 to 15 minutes because anesthetic uptake is too great
  (b) System volume must be more closely monitored
  (c) Increased CO_2 absorbent use
  (d) N_2O cannot be used without an O_2 monitor in the system

b. Flow rates in excess of 4 to 6 mL/kg/min require an open pressure relief valve (semi-closed)

D. Humphrey-ADE circle system (ANAEQUIP International) (Fig. 12-10)
1. Developed as an economical, portable multipurpose system for small-animal veterinary practice with or without recycling through a soda-lime canister



FIG. 12-10. The Humphrey-ADE circuit consists of a block, a fresh gas inlet (*FG*), two breathing bag connectors (*B1* and *B2*), an adjustable expiratory valve (*V*), connectors for the animal (*P*) tubing (parallel, as shown, or coaxial), and a rotary selector valve (*darker color*). The circuit design (i.e., Mapleson A, D, or E) is determined by the position of the selector valve and which bag connector is used. The four-phase exhaust or pop-off (*V*) valve is designed with a sleeve or chimney that opens and closes in four distinct phases. A spindle connected to the valve seat lifts with expiration, enabling respiration to be monitored. Putting a finger on the spindle closes the valve and allows manual ventilation.

a. Semi-closed mode for small animals weighing less than 10 kg
b. Recycling through soda lime for larger animals
c. Lower fresh gas flows in both modes especially compared with the Bain or T piece
d. Unique self-regulating four-phase expiratory valve
   (1) The exhaust ("pop-off") valve on the ADE-circle system is designed with a sleeve or chimney around the rim and opens and closes in four distinct phases
   (2) Putting a finger on the top of the valve closes the valve and allows manual ventilation without closing the valve

2. Combines semi-closed systems (nonrebreathing): Lack, Magill, Bain, Bain. T piece anesthetic circuit: Ayres T piece in one breathing system
3. The Mapleson A circuit is inefficient for controlled ventilation, as is the Mapleson D circuit for spontaneous ventilation
   a. David Humphrey has designed a single circuit that can be changed from a Mapleson A system to a Mapleson D. The reservoir bag is situated at the fresh gas inlet.

Veterinary Anesthetic Machines

I. Machines are currently manufactured for veterinary use by the following companies:

A. A.M. Bickford: several small-animal models (Wales Center, New York, www.ambickford.com)
B. ANAEQUIP International & United Kingdom Contact Centre. Anaequip-Vet UK (Shrewsbury, UK, http://www.anaequip.com/index.htm)
C. AnescoSurgivet/Smith Medical: a variety of anesthetic machines, and ventilators for small and large animals (Waukesha, Wisconsin, www.surgivet.com)
D. DRE Veterinary: small-animal machine (Louisville, Kentucky, www.dreveterinary.com)
E. Engler Engineering: small-animal combination ventilator/anesthetic machine (Hialeah, Florida, www.englerusa.com)
F. Hallowell Engineering and Manufacturing: a variety of anesthesia ventilators and accessories (Pittsfield, Massachusetts, www.hallowell.com)

G. Highland Medical Equipment: a variety of small-animal machines (Temecula, California, www.highlandmedical.net)
H. IM3: in-circle vaporizer for small animals (Vancouver, Washington, www.im3vet.com)
I. J. D. Medical: several small- and large-animal machines with ventilators (Phoenix, Arizona, www.jdmedical.com)
J. Mallard Medical: small- and large-animal machines and ventilators (Redding, California, www.mallardmedical.net)
K. Matrx: several small-animal machines and ventilators and one large-animal machine (distributed by Midmark, Versailles, Ohio, www.midmark.com)
L. Moduflex Anesthesia Equipment: small-animal anesthesia machines (San Diego, California, www.moduflexanesthesia.com)
M. Summit Hill: waste gas scavenging equipment (Tinton Falls, New Jersey, http://summithilllaboratories.com)
N. Vetland: small- and large-animal anesthesia machines (Louisville, Kentucky, www.vetland1.com)

II. Veterinary machines no longer manufactured
A. Dupaco compact 78: small-animal machines
B. North American Dräger Narkovet: small- and large-animal machines
C. Pitman-Moore: 970, 980, and Vetaflex-5

III. Used human anesthesia machines are available through most anesthesia equipment dealers

Cleaning And Disinfecting

I. Breathing hoses and reservoir bags should be cleaned and disinfected after each use
A. Wash with hot, soapy water and rinse
B. Soak in a cold disinfectant solution such as Nolvasan or Cidex and thoroughly rinse
C. Clean the external surfaces of the anesthetic machine daily with a spray cleaner
D. Occasionally disassemble the dome valves and absorbent canister and wipe dry

II. Gas or steam autoclaving is not necessary unless gross contamination is present

III. Anesthetic machine check (Boxes 12-1 and 12-2)
A. Verify proper machine function before each use; some checks should be performed daily, others before each use

BOX 12-2

Preanesthesia Equipment Checklist

I. O_2 Source:
   A. Leak-check O_2 cylinder: open valve
   B. Ensure adequate tank pressure: >500 psi
   C. Ensure extra O_2 tanks available
   D. Leak-check piped O_2: attach gas line

II. Flowmeters
   A. Ensure float/bobbin moves freely through full flow range

III. Vaporizers
   A. Filled, caps securely fastened
   B. Dial freely moveable and in OFF position

IV. Scavenging system
   A. House scavenger attached
   B. F/air canister attached, <50 gr weight gain

V. Breathing system
   A. Nonrebreathing system: patient <5 to7 kg
   B. Rebreathing (circle) system
      1. Soda lime full, acceptable quality (moist/crumbly)
      2. One-way valves present, competent
      3. Reservoir bag of appropriate size (50 mL/kg)
      4. Pop-off valve checked and in fully open position

VI. Electronic equipment/monitoring equipment
   A. Ensure batteries are charged, devices are plugged in and operational

VII. Pressure checking the anesthesia machine
   A. Nonrebreathing system
      1. Ensure the flowmeter is off
      2. Close the pop-off
      3. Occlude the patient end of the breathing circuit
      4. Depress the O_2 flush button to pressurize the circuit to 20 cm H_2O
      5. Observe the pressure gauge; if loss of pressure is noticed slowly titrate the O_2 flowmeter up to quantitate the rate of gas leak, <500 mL/min is acceptable. If >500 mL/min, check the machine to find the leak

VIII. Rebreathing system
   A. Ensure the flowmeter is off
   B. Occlude/close the pop-off (if present on) or crimp the tubing leading to the scavenge system
   C. Depress the O_2 flush button to pressurize the circuit to 20 cm H_2O
   D. Observe the pressure gauge, if loss of pressure is noticed slowly titrate the O_2 flowmeter up to quantitate the rate of gas leak, <500 mL/min is acceptable. If >500 mL/min, check the machine to find the leak

XI. Coaxial circuits—check the inner tube
   A. Turn the O_2 flowmeter on to ~3 L/min
   B. Occlude the INNER (blue) tube to the coaxial breathing circuit (end of a pen, end of a syringe case, etc.)
   C. Observe a drop in the bobbin/float drop in the flowmeter due to back pressure buildup in the anesthesia machine

B. Consult the owner's manual for manufacturer's recommendations

Troubleshooting Anesthetic Equipment Problems

I. Rebreathing bag is empty or does not stay inflated
- A. Flow rate is too low or the flowmeter control knob is turned off
- B. System leak
  1. Gasket on CO_2 canister improperly installed
  2. Hole in rebreathing bag or tubing
  3. Leak in endotracheal tube cuff
  4. Waste-gas scavenging system using active suction improperly regulated
  5. Water drain near CO_2 absorbent canister is open

II. Rebreathing bag is overly distended (positive pressure in circuit)
- A. Pressure relief valve inadvertently left closed
- B. Flow rate too high in closed system
- C. Waste-gas scavenging system improperly regulated

III. Animal seems "light"
- A. Vaporizer empty, not working properly, or on an inadequate setting
- B. Excessive CO_2 buildup
  1. Exhausted CO_2 absorbent
  2. Sticky unidirectional valve
- C. Vaporizer needs service
  1. Water buildup on wick
  2. Recalibration necessary
- D. Animal receiving hypoxic gas mixture
  1. N_2O flowmeter set too high relative to O_2 flow
  2. O_2 cylinder(s) filled with wrong gas

IV. Animal seems "deep"
- A. Vaporizer set too high or not working properly
- B. More than one vaporizer activated
- C. Animal severely hypercarbic or hypoxic
- D. Animal is hypotensive

Waste Anesthetic-Gas Pollution

I. Waste anesthetic gases are anesthetic vapors that escape the animal and/or the anesthetic equipment (circuit) and enter the environment

II. Environmental pollution and staff exposure occur when anesthetic waste gases leak into the environment

III. Health concerns
- A. Adverse effects associated with chronic exposure to trace levels of waste gases are conjectured to be associated with increased incidence of infertility, spontaneous abortion, birth defects, neoplasia, hepatic and renal disease, neurologic disturbances, hematopoietic changes, and pruritus
  1. Individuals at highest risk
     a. Persons with preexisting hepatic or renal disease
     b. Persons with immune system compromise
     c. Women in the first trimester of pregnancy
- B. Epidemiologic studies, animal studies, and human volunteer studies reveal conflicting evidence
  1. To date, there is no definitive cause-and-effect relationship between exposure to waste gases and disease
  2. Overall evidence implies a potential hazard

IV. Environmental concern
- A. N_2O
  1. A greenhouse gas (implicated in global warming)
- B. Halogenated hydrocarbons
  1. Ozone layer depletion

V. Regulations regarding waste anesthetic gas levels
- A. Standards for maximum allowable concentrations have been established by the National Institute for Occupational Safety and Health (www.osha.gov/dts/osta/anestheticgases/)
- B. Recommended acceptable levels
  1. Volatile agents used alone: less than 2 parts per million (ppm)
  2. Volatile agents combined with N_2O: less than 0.5 ppm
  3. N_2O: less than 25 ppm
  4. Levels are time-weighted averages over the span of surgical procedure(s)

VI. Collecting and removing waste gases
- A. Scavenging is the collection and removal of waste gases from the anesthetic system and the workplace (Fig. 12-11)
- B. Scavenging systems are made up of the following major components:
  1. Pressure relief valve (pop-off)
     a. Diverts excess gases for removal from the anesthetic circuit system
     b. May need to be modified or replaced for leak-free connection

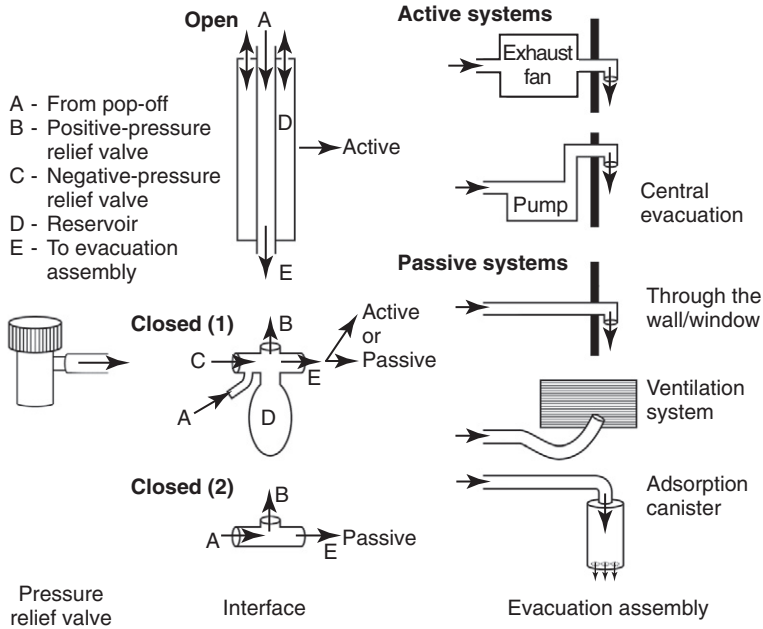


FIG. 12-11. Different methods for scavenging waste anesthetic gases. Note: passive systems are recommended because active systems have the potential to draw gas from the anesthetic circuit (increase waste).

c. In nonrebreathing circuits, waste gases are scavenged from the reservoir bag

2. Interface
   a. Protects breathing circuit and patient from excessive positive or negative pressures
   b. Located between the pop-off valve and the disposal system
   c. Open interfaces contain no valves and are open to the atmosphere
      (1) Best suited for use with high-flow active evacuation systems
      (2) Must have reservoir to buffer pressure differences
      (3) Safety depends on the number of vents
      (4) Economical and easily made
   d. Closed interfaces contain mechanical pressure relief valves
      (1) Best suited for use with low-flow active or passive evacuation systems

(2) Positive-pressure relief valve (pressure relief valve) protects system from pressure buildup if the line is occluded
(3) Negative-pressure relief valve required for use with active evacuation system
(4) Does not require a reservoir, except when active evacuation is used
(5) More costly, but safer and more versatile

3. Evacuation systems
   a. The evacuation system moves the collected waste gases to a remote area for release
   b. Passive evacuation systems
      (1) The flow of gases is controlled by ventilation
      (2) Gases are exhausted into a nonrecirculating ventilation system, directly out into the atmosphere
      (3) Inexpensive and easy to install
      (4) Inefficient and a potential hazard to the patient because of potential resistance to exhalation
   c. Active evacuation systems
      (1) Mechanical flow-inducing devices
      (2) Consist of a central vacuum system or a dedicated fan or pump
      (3) Negative pressure produced requires an interface with a negative pressure relief valve
      (4) More costly and complex than passive systems
      (5) More effective than passive systems
   d. Activated charcoal absorption canisters
      (1) Remove hydrocarbons
      (2) Do not remove N_2O
      (3) Require frequent replacement
4. Transfer tubing
   a. Connects the different components of the system
   b. Tubing should be resistant to kinking, easily differentiated from the breathing circuit, and able to transfer high flows
   c. Tubing for passive systems should be as short and wide as practical

VII. Additional control methods

A. Pressure check all breathing circuits and machines for leaks (see Box 12-2)

B. Use inhalant-specific bottle cap adaptors when filling vaporizers to avoid spillage and fill at the end of the workday when fewer people are present
C. Use low-flow or closed-system techniques if experienced with them
D. Check endotracheal tube cuff for leaks before use and be sure it is adequately inflated during use
E. Avoid chamber and mask inductions; when they cannot be avoided, use tight-fitting mask and attach scavenger tubing to chamber
F. Ventilate areas where inhalant anesthesia is commonly used and areas where animals are recovering; remain at least 1 m from the recovering patient's head
G. If the anesthetic circuit is primed, be sure to occlude the Y-piece until it is connected to the orotracheal tube
H. When disconnecting the patient from the breathing circuit, turn off flowmeter and vaporizer, occlude Y piece, and evacuate remaining gas in the system into the scavenger
    1. Recover the animal in an area that is well ventilated and does not recirculate ventilated gases into the hospital air-flow system
I. Wear a half-mask respirator if waste gases cannot be avoided
J. Inform all employees of potential risks associated with waste gas exposure and emphasize measures to reduce exposure

13 Ventilation and Mechanical Assist Devices

"You don't need a weatherman to know which way the wind blows."
BOB DYLAN

OVERVIEW

A crucial aspect of providing safe general anesthesia is maintaining normal ventilation. Normal ventilation is defined by the maintenance of normal arterial blood carbon dioxide ($PaCO_2$) concentrations. Respiratory effort is routinely assessed by observing the movements of the animal's chest and abdominal wall. Although chest wall movements may be regular and give the appearance of satisfactory gas exchange, they do not ensure adequate movement of air in and out of the lungs. Gas exchange is improved by inflating the lungs to a predetermined pressure or predetermined volume by manually squeezing a rebreathing bag on an anesthetic machine, or by attaching the endotracheal tube to mechanical ventilatory-assist device (ventilator). Controlled (rate and volume) ventilation helps maintain a more stable plane of anesthesia because the lungs are the exchange site for inhalant anesthetic uptake and elimination. High-frequency ventilation is a unique technique based on the principle that diffusion is the primary means by which fresh gases are delivered to peripheral airways for gas exchange.

General Considerations

I. Manual or mechanical intermittent positive pressure ventilation (IPPV) when properly applied can be used to maintain stable inhalant anesthesia (the drug delivery system is the lung) and blood gases (PO_2, PCO_2) for prolonged durations with minimal untoward effects

II. Positive pressure ventilation requires a thorough familiarity with cardiopulmonary physiology, ventilatory equipment and techniques, and blood gas interpretation

III. Mechanical ventilators inflate the lungs to a predetermined volume (volume cycled) or pressure (pressure cycled) or for a preset time at a predetermined gas flow rate (time cycled). Most

anesthesia ventilators consist of a compliant pleated compressible bellows connected to an anesthetic breathing circuit. The bellows is contained within an airtight rigid plastic cylinder that can be pressurized to compress the bellows. Driving gas is cyclically introduced into the cylinder (outside the bellows) causing pressure within the cylinder to increase (inspiratory phase). The bellows is compressed and gas contained therein is delivered to the airway. When pressure within the cylinder is released, the process reverses and the elastic recoil of the lung causes the bellows to expand (expiratory phase).

A. The breathing circuit must be airtight (no leaks; "closed circuit") during the inspiratory phase of the ventilation cycle for gas to be directed into the airway and lungs

IV. Controlled ventilation may be required in animals that are not breathing adequately or that are difficult to keep anesthetized

V. $PaCO_2$ values and capnometry ($ETCO_2$) provide continuous assessment of ventilatory adequacy (see Chapter 14)

Reasons for Respiratory Inadequacy

I. Depression of respiratory centers
- A. Drug-induced
  1. Anesthesia
  2. Analgesics (opioids)
  3. Drug toxicities
- B. Metabolic
  1. Acidosis ($PaCO_2 > 70$ mm Hg; metabolic acidosis)
  2. Coma
  3. Toxic metabolites (endotoxins)
- C. Physical
  1. Head trauma (increased intracranial pressure)

II. Inability to adequately expand the thorax
- A. Drug induced
  1. Neuromuscular blocking drugs
- B. Pain (splinting of chest)
- C. Chest wall trauma
- D. Thoracic surgery
- E. Abdominal distention
- F. Muscle weakness
- G. Obesity
- H. Bony deformities of the chest wall
- I. Positioning

1. Weight of abdominal viscera on the diaphragm may impede lung expansion
2. Head-down position
3. Surgical tie downs and abnormal thoracic limb positioning

J. Nerve trauma or edema

III. Airway obstruction including laryngeal paralysis
- A. Foreign and bodily materials (e.g., stones, sticks, water, mucus, blood)
- B. Trauma (nasal, laryngeal, trachea)
- C. Infection and inflammation
- D. Neoplasia
- E. Congenital anomalies (e.g., collapsed trachea or bronchi)
- F. Nerve disease or damage

IV. Inability to adequately expand the lungs
- A. Pneumothorax (especially tension pneumothorax)
- B. Pleural fluid
- C. Diaphragmatic hernia
- D. Lung disease
- E. Neoplasia
- F. Pneumonia
- G. Atelectasis

V. Cardiopulmonary arrest

VI. Pulmonary edema or insufficiency

Managing Ventilation during Anesthesia

I. Anesthetics are respiratory depressants; positive pressure ventilation may be required to assist or control breathing
- A. Controlled ventilation helps to ensure adequate alveolar ventilation, aiding in the uptake (inhalants) and elimination of drugs and gases

II. Special indications for controlled ventilation during anesthesia
- A. Thoracic surgery
  1. Controlled respirations minimize spontaneous chest wall movements
  2. The lungs cannot be inflated when the chest is open (intrathoracic pressure equals atmospheric)
- B. Neuromuscular blockers (see Chapter 10): neuromuscular blocking drugs paralyze the diaphragm and intercostal muscles producing apnea
- C. Prolonged surgical anesthesia (more than 60 minutes) reduces respiratory effort, especially in horses, resulting in hypoventilation

D. Chest wall or diaphragmatic trauma
   1. Broken ribs
      a. "Flail chest": series of adjacent broken ribs resulting in the segment moving independently (chest wall moves in during inspiration instead of out: paradoxical breathing). Usually associated with lung contusion and pneumothorax.
   2. Space-occupying lesions
      a. Diaphragmatic hernia
      b. Blood, fluid, neoplasia
E. Maintain a more stable plane of anesthesia
F. Obesity and special positioning
G. Control of intracranial pressure
H. Convenience: eliminate concerns about hypoventilation and poor gas exchange (low oxygen [O_2]; high carbon dioxide [CO_2])

Considerations for and Consequences of Ventilation

I. Pulmonary system
   A. Normal lungs are well ventilated during spontaneous breathing (Fig. 13-1)
      1. Inspiration is active and dependent upon the integrated function of the nervous and musculoskeletal systems
      2. Expansion of the rib cage and flattening of the diaphragm increase the volume of the thoracic cavity and the negative pressure in the thoracic cavity, drawing air into the lung

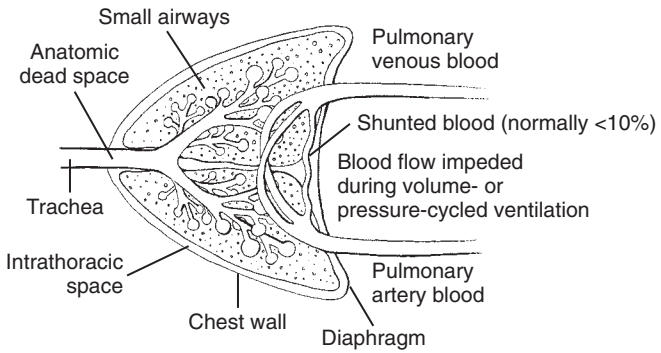


FIG. 13-1. Anatomic drawing of various components of the lung and its blood supply. Cyclical changes or constant increases in lung volume and airway pressure can impede blood flow through the lung. The intrathoracic space is a potential space that can expand (e.g., pneumothorax, hemothorax).

3. Expiration is passive returning lung volume to its original state
    a. The balance between the ribs' tendency to spring outward and the lungs' elastic tendency to collapse determines the initial lung volume

B. The portions of the lung in closest contact with moving surfaces (i.e., the peripheral lung field, diaphragm) undergo the greatest volume changes during spontaneous ventilation

C. Decreased breathing of hypoventilation causes increases in CO_2 ($PaCO_2 > 45$ to 50 mm Hg)
1. Results in respiratory acidosis
2. Activates the sympathetic nervous system
3. Predisposes to cardiac arrhythmias
    a. Caused by sympathetic stimulation and hypoxemia
4. Initially causes peripheral vasoconstriction (sympathetic effect) followed by peripheral vasodilation as a direct effect of CO_2 on smooth muscle tone
    a. Increases cerebral blood flow and intracranial pressure
5. Increased $PaCO_2$ can produce narcosis
    a. $PaCO_2$ levels above 80 to 100 mm Hg have an anesthetic effect
6. Hyperpnea and an increased work of breathing

D. Positive pressure ventilation inflates the peribronchial and mediastinal areas of the lung; the peripheral segments are relatively less ventilated compared with normal spontaneous breathing
1. Pressure or volume ventilation increases airway diameter and thus anatomic dead space, reducing alveolar ventilation

E. Positive pressure ventilation results in a significant reduction in lung compliance; the lung becomes stiffer and predisposes to atelectasis and hypoxemia
1. Small-airway closure can occur
2. The distribution of ventilation is altered, leading to ventilation-perfusion mismatching
3. Ventilators that deliver a preset volume compensate for stiffer lungs by ensuring delivery of a constant volume independent of airway pressure

II. Cardiovascular system (Table 13-1)

A. The subatmospheric pressure within the thorax augments venous return during inspiration; this subatmospheric pressure is made more negative during inspiration by contraction of the diaphragm

TABLE 13-1 Cardiovascular System: Effects of Breathing and Intermittent Positive Pressure Ventilation

Phase of Cycle	Intrathoracic Total Pressure	Total Thoracic Blood Volume	Left Ventricle Cardiac Output
NORMAL BREATHING			
Inspiration active	(–5 cm of H_2O)	↑	↓
Expiration passive	↑(–2 cm H_2O)	↓	↑
IPPV			
Inspiration passive	↑(10-20 cm H_2O)	↓	— (↓ if IPP prolonged)
Expiration generally passive	↓To atmospheric pressure	↑	↓

IPP, Intermittent positive pressure; IPPV, intermittent positive pressure ventilation.

B. The pressure in the airway and lungs is transmitted to the thoracic cavity during controlled ventilation, impeding venous return and potentially decreasing cardiac output (see Fig. 13-1; Fig. 13-2)
C. Controlled ventilation decreases arterial blood pressure and cardiac output when:
   1. Average airway pressure is consistently more than 10 mm Hg
   2. Circulating blood volume is low, caused by dehydration and blood loss
   3. Sympathetic nervous system activity is impaired, caused by anesthesia, local anesthetics, and shock
D. Controlled ventilation decreases venous return and pulmonary blood flow and may lead to ventilation-perfusion abnormalities
E. Hemodynamic changes during controlled ventilation are caused by prolonged increases in mean airway pressure, decreases in venous return and cardiac output, and changes (decreased; increased) in CO_2

III. Normal values (Fig. 13-3)
A. Tidal volume (V_T): the amount of gas exchanged in one respiratory cycle
   1. 10 to 15 mL/kg of body weight
   2. Ventilator bellows volume is usually increased by 2 to 4 mL/kg over normal V_T (10 to 12 mL/kg) during intermittent positive-pressure breathing in dogs and cats

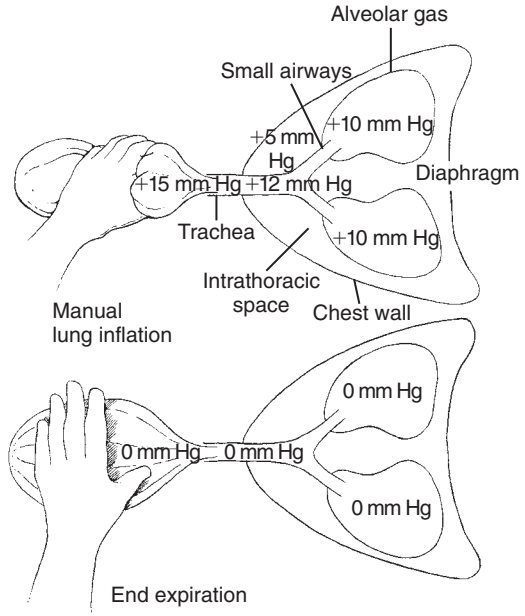


FIG. 13-2. Manual lung inflation produces a positive pressure in the lungs, which is transmitted to the intrathoracic space, reducing lung blood flow and lowering cardiac output. Pressure values reflect changes relative to atmospheric pressure.

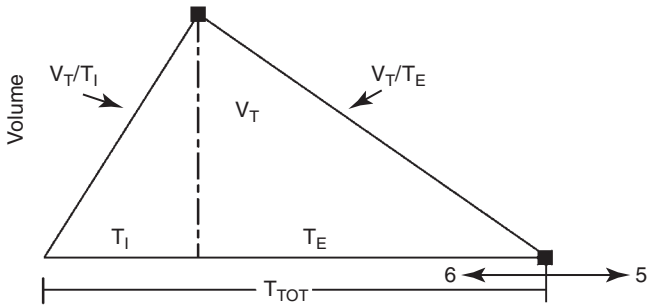


FIG. 13-3. Important components of the breathing cycle include tidal volume (V_T; mL) and inspiratory (T_I) and expiratory time (T_E). The T_E should always be longer than the T_I and is used on many ventilators to determine the respiratory cycle I:E ration.

to compensate for the increased positive pressure-induced volume of the breathing hoses and conducting airways (wasted ventilation). This volume is larger in horses and cattle.

B. Minute volume (V_m): the volume of gas exchanged in 1 minute
   1. Determined by V_T and breaths per minute (BPM): $V_T \times BPM = V_m$

C. Adequate inflation of the normal lungs requires approximately 15 to 20 cm H_2O pressure or 10 to 12 mL/kg; lung compliance (volume/pressure/kg) is important in determining the pressure required to inflate the lung

D. The spontaneous ventilatory cycle
   1. Inspiration (I) is active
      a. One second in small animals
      b. From 1.5 to 2 seconds in large animals

E. Controlled ventilation in the normal patient (Table 13-2, Fig. 13-4)
   1. V_T (10 to 12 mL/kg)
   2. Pressures
      a. From 15 to 20 cm H_2O in small-animal species with normal lungs; 20 to 30 cm H_2O in large-animal species with normal lungs
      b. Pressures may be higher during open-chest procedures or in the presence of "stiff" or mechanically inhibited lungs

TABLE 13-2 Initial Setting for Pulmonary Versus Extrapulmonary Pathology

Parameter	Normal Lungs	Abnormal Lungs
F_IO_2	100% initially	—
V_T	8-15 mL/kg	—
Respiratory rate	8-15 breaths/min	—
Minute ventilation	150-250 mL/kg/min	—
PIP	10-20 cm H_2O	12-25 cm H_2O
PEEP	0-2 cm H_2O	2-8 cm H_2O
Trigger sensitivity	–2 cm H_2O or 2 L/min	—
I:E ratio	1:2	—
Inspiratory time	Approximately 1 sec	—

F_IO_2, Fraction of inspired oxygen; I:E ratio, inspiratory time to expiratory time ratio; PEEP, positive end-expiratory pressure; PIP, peak inspiratory pressure; V_T, tidal volume.

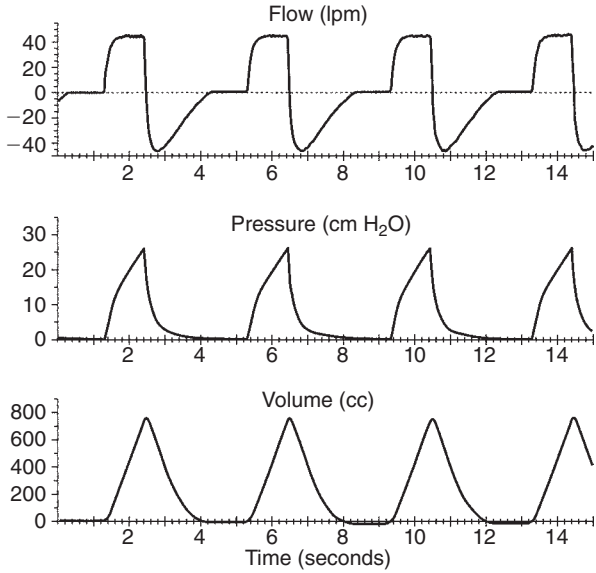


FIG. 13-4. Flow, pressure, and volume (V_T) waveforms associated with intermittent positive pressure ventilation (IPPV). Note the timing and changes in flow and pressure associated with the increase or decrease in volume during a single breath.

3. Inspiration time/expiration time (I:E) ratios; can be preset and vary based on rate, V_T, and inspiratory time (T_I)
   a. From 1:2 to 1:3 in small animals
   b. From 1:2 to 1:4.5 in large animals
4. T_I during controlled ventilation
   a. Approximately 1 to 1.5 seconds in smaller animals
   b. Less than 2 to 3 seconds in large animals (e.g., 1.5 seconds in a 450 kg horse)

Ventilator Classification

I. Volume preset (cycled) ventilators (Fig. 13-5)
   A. A predetermined volume of gas or gas mixture is delivered
      1. Delivers a known V_T regardless of the pressure imposed
         a. Most volume-cycled ventilators are equipped with a pressure release safety valve to prevent the development of extremely high inspiratory and system pressures (more than 50 to 60 cm H_2O)
      2. Deliver a constant volume despite changes in airway pressure caused by changes in lung compliance and airway resistance during anesthesia

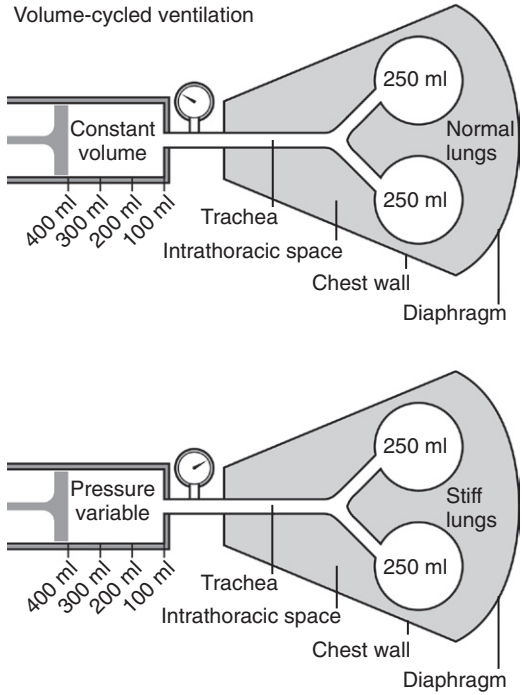


FIG. 13-5. Volume preset (volume cycled) ventilation delivers a constant volume of gas. The pressure is variable. If the lung becomes stiffer (bottom), the pressure (note: pressure indicator) required to deliver a constant volume increases.

3. High airway pressures may develop in stiff (fibrosis, edema) or inflamed lungs
4. Volume cycled ventilators do not compensate for small leaks in the breathing circuit
   a. Require an airtight circuit; a major leak prevents the animal from receiving an adequate V_T
5. Piston or bellows-type ventilator delivers a predetermined volume

II. Pressure preset (cycled) (Fig. 13-6)

A. A gas or gas mixture is delivered by a ventilator until the system reaches a preset pressure

B. Advantages
   1. High safety factor; high pressure will not develop unless preset by the operator
   2. Compensates for small leaks; large leaks prolong T_I

C. Disadvantages

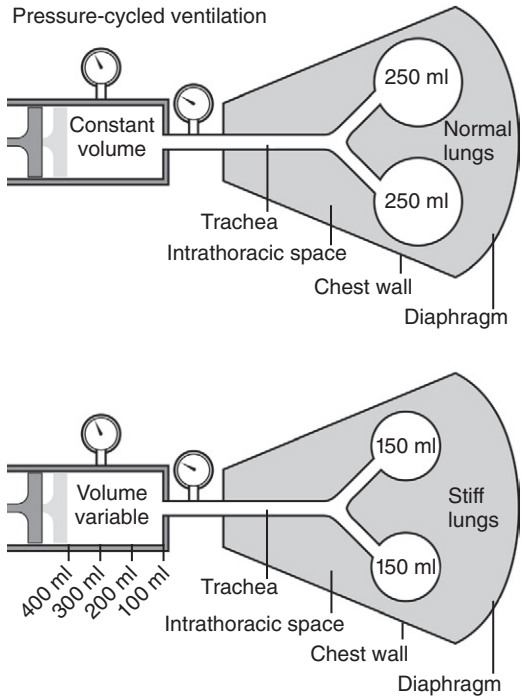


FIG. 13-6. Pressure-preset (pressure cycled) ventilators deliver a predetermined pressure regardless of the volume delivered. Sudden or progressive increases in inspiratory time during pressure-cycled ventilation suggest a leak (incompetent endotracheal tube cuff or pop-off valve) in the anesthetic circuit.

1. Volume delivered is variable and depends on the animal's:
   a. Lung compliance
   b. Airway resistance
   c. Number of functional alveoli
   d. Pressure within the thorax
2. Determination of V_T delivered may be difficult if the ventilator is not equipped with bellows or a respirometer
3. Pressure may increase during a procedure to maintain constant V_T

III. Time cycled: most anesthesia ventilators can be adjusted to limit the volume of gas delivered or the pressure developed during inspiration by adjustments of :

A. I:E ratio
B. Respiratory rate (f)
C. Inspiratory flow rate

D. T_I (most modern anesthesia ventilators provide the ability to control T_I)

IV. Anesthesia ventilators classified by bellows movement during expiration
   A. Ascending ("standing"): bellows rise during expiratory phase
      1. Leaks are easily identified and bellows will not return to its full height
   B. Descending (hanging"): bellows fall during expiratory phase

Modes of Operation

I. Assist mode: inspiratory effort triggers the ventilator to deliver a breath
   A. The operator determines (presets) the inspiratory pressure or the delivered volume

II. Controlled mode (most modern anesthesia ventilators operate in a controlled mode)
   A. Operator sets the desired respiratory rate and the inspiratory pressure or the delivered volume

III. Assist-controlled mode: operator sets a minimum respiratory rate and the inspiratory pressure or the delivered volume
   A. The animal may spontaneously breathe at rates greater than the preset rate (override)

IV. Intermittent mandatory ventilation: operator sets a predetermined number of positive breaths; the animal also breathes spontaneously through a parallel breathing circuit

Terms Used To Describe Airway Pressures during Respiratory Cycle

I. **IPPV** (intermittent positive pressure ventilation): positive pressure maintained only during inspiration

II. **IMV** (intermittent mandatory ventilation): a predetermined number of positive breaths are set by the operator; the animal also breathes spontaneously through a parallel breathing circuit

III. **CPPV** (continuous positive pressure ventilation): mechanical ventilation with positive pressure maintained during inspiration and at lower pressure on expiration

IV. **PNPV** (positive/negative pressure ventilation): positive pressure during inspiration and negative pressure during expiration

V. **PEEP** (positive end-expiratory pressure): Airway pressure is positive during entire respiratory cycle. It is used to open small airways or prevent atelectasis.

VI. **ZEEP** (zero end-expiratory pressure): normal passive expiration

VII. **NEEP** (negative end-expiratory pressure): used to hasten expiration
VIII. **CPAP** (continuous positive airway pressure): spontaneous breathing with positive pressure during both inspiratory and expiratory cycles

Ventilators Commonly Used in Veterinary Medicine

Most ventilators used during general anesthesia connect to the anesthesia breathing system at the site where the rebreathing bag attaches (Fig. 13-7)

I. Mallard Medical microprocessor-controlled small- and large-animal anesthesia ventilators
   A. Classification: Ascending bellows; time cycled, microprocessor controlled
   B. Controls
      1. Inspiratory flow rate
      2. Respiratory rate
      3. T_I
   C. Volume, I:E ratio, and pressure delivered are a function of adjustments in inspiratory flow rate, respiratory rate, and T_I
   D. Ventilator bellows connects to rebreathing bag mount of circle system
   E. PEEP capability
II. Hallowell EMC 2000 and 2002 time-cycle small-animal ventilator (also sold by Midmark, Inc., as Matrix 3000)
   A. Ascending bellows
   B. V_T adjustable from 0 to 3000 mL
   C. Adjustable I:E ratio available
   D. Volume and pressure delivered are a function of adjustments in frequency, T_I, and I:E ratio
   E. Interchangeable bellows sizes can be purchased for animals weighing 1 to 200 kg
III. SurgiVet SAV 2500-Small Animal Anesthesia Ventilator
   A. Ascending bellows
   B. Time cycled with adjustments for inspiratory flow rate and T_I
   C. V_T adjustable from 0 to 3000 mL
IV. SurgiVet Large Animal Ventilator
   A. Classification: volume preset; descending bellows; time cycled
   B. Volume delivered depends on frequency, inspiratory flow rate, and T_I
V. Engler ADS 1000
   A. Microprocessor controlled

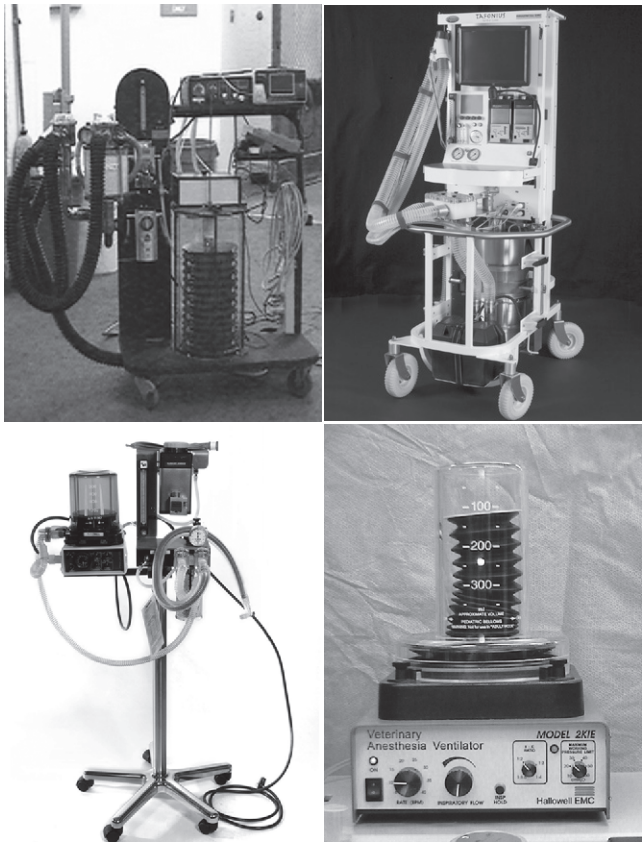


FIG. 13-7. Mechanical ventilators are used to provide intermittent positive pressure ventilation in large (*top: Mallard; Hallowell-Tafonius*) and small (*bottom*) animals. Both pressure (15 to 20 cm H_2O) and volume (10 to 15 mL/kg) should be monitored. Arterial blood gas values (PO_2, PCO_2) are used to determine the efficacy of mechanical ventilation. Note the ventilator bellow may be "standing" (upper right and bottom two figures) or "hanging" (upper left). Standing bellows are preferred because they indicate a circuit leak if the bellows does not refill during expiration.

B. Can be used with a vaporizer for anesthesia or without a vaporizer
C. Nonrebreathing circuit principle of operation
   1. No CO_2 absorbent necessary
   2. No conventional anesthesia breathing circuit necessary
D. Machine automatically selects ventilation parameters based on patient weight
E. PEEP capability

VI. North American Dräger Large and Small Animal Anesthetic Ventilator
- A. Classification: volume-preset ventilator; time cycled; descending bellows with adjustable inspiratory flow rate
  1. Volume is adjusted by raising and lowering bellows support to appropriate level
  2. Pressure manometer indicates the pressure within the system
- B. Controls
  1. Frequency is adjusted to breaths/minute
  2. Inspiratory flow rate is adjustable; inspiratory flow rate determines T_I
  4. I:E ratio is adjustable from 1:1 to 1:4.5
  5. Adjustment of flow rate, I:E ratio, and T_I determines delivered volume
- C. Pressure relief valve
  1. Manual pressure relief valve of breathing system must be closed during ventilator use
  2. Automatic pressure relief closes with the inspiratory cycle

VII. JD Medical anesthetic machine, models LAVC 2000, 2000 D, 2000 D2
- A. Classification: pressure-preset ventilator; descending bellows
- B. Large-animal ventilator
  1. Bellows within the cylinder is compressed by the flow generated by a modified Bird Mark 7 ventilator
  2. Volume is indicated on the chamber encasing the bellows
  3. The pressure and f can be adjusted for the desired volume
- C. Mode
  1. Assisted: the sensitivity can be adjusted so that the patient can trigger the machine
  2. Controlled: the value of sensitivity can be decreased so that the patient cannot trigger the machine
  3. Assist-controlled: the operator can control the minimum number of breaths delivered; the patient can also trigger ventilator operation
- D. Controls
  1. Inspiratory pressure
     a. Usually set at 20 to 30 cm H_2O
     b. Adjusted for the desired V_T
  2. Expiratory time

a. Controls respiratory rate by controlling time between breaths
b. Rate usually set at 6 to 10 breaths/minute for horses

3. Flow rate (adjust to an T_I of 1.3 to 2 seconds for horses)
4. Air mix: pull air mix knob to "out" position
   a. Set at 50% to conserve O_2
   b. Does not affect O_2 supply to the animal
5. Sensitivity
   a. Governs the animal's ability to trigger the ventilator
   b. Numbers are merely a rough guide to indicator of position

VIII. Bird Mark 7 and Bird Mark 9 ventilators

A. Classification: pressure preset ventilator; volume delivered is controlled by the pressure developed unless the machine is equipped with a bellows
B. Must be equipped with a bag-in-a-barrel or a bellows to be used as an anesthetic system; otherwise, it can stand alone as an intensive care ventilator
C. Controls
   1. Inspiratory pressure
      a. Controls peak pressure
      b. Normally set at 15 to 30 cm H_2O
   2. Sensitivity
      a. Controls animal's ability to trigger the machine
      b. Low numbers; easily triggered
      c. High numbers; difficult to trigger
   3. Inspiratory flow rate
      a. Controls T_I
      b. Set equal to or less than expiratory time
   4. T_E
      a. Controls respiratory rate by controlling expiratory time
      b. Respiratory rate is normally 6 to 12 breaths/minute
   5. Air mix
      a. Varies percentage of inspired O_2 from 50% (knob out) to 100% (knob in)
      b. Negative pressure: (Bird Mark 9 only) allows the operator to produce NEEP

High-Frequency Jet Ventilation

I. High-frequency jet ventilation is a form of ventilation in which f is greater than 60 cycles/min, and V_T is less than anatomic dead space (Fig. 13-8)

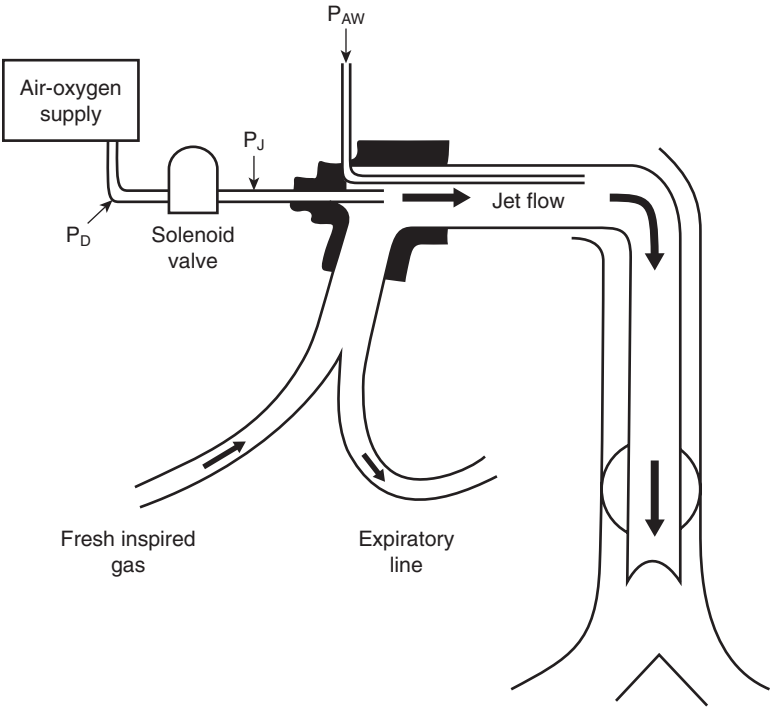


FIG. 13-8. High-frequency jet ventilation (HFJV) requires special equipment. The technique employs an open breathing system, so there is no need for an airtight connection between the airway and the breathing system. P_D = driving pressure; P_J = jet pressure; P_{AW} = airway pressure.

A. High-frequency jet ventilation is used to produce apnea thereby minimizing breathing effects and chest wall movement while maintaining adequate oxygenation
B. Potential uses include acute respiratory distress, laryngeal surgery, pulmonary edema, hyaline membrane disease, bronchopleural fistula, and pulmonary contusion and ventilation during bronchoscopy
C. Initial settings for HFJV via a subglottic catheter are driving pressure (DP), 2 atm; **f**, 150 min **2**1; $\mathbf{F}_I O_2$, 1.0; Inspiratory time, 50%
D. Advantages and Disadvantages of jet ventilation

	Advantages	Disadvantages
Physiologic	Reduced peak airway pressure.	Potential risk of barotrauma.
	Hemodynamic compromise less than IPPV.	Cooling and drying of conditioned inspiratory gases by expansion at nozzle.
		Efficacy of gas exchange varies, e.g. obesity, COPD.
	Reduced ADH production and fluid retention.	Delivered F_IO_2 is multifactorial.
		Collateral ventilation increases effective dead space.
Surgical	Minimal vocal cord/surgical field movement.	Potential for lower airway contamination.
	Improved visibility and surgical access.	Contamination of expired gas flow by surgical debris.
Anesthetic	Good in low resistance large volume airway leak.	Inhalational anesthesia often impractical.
	Emergency trans-tracheal jet ventilation.	Contamination of operating room air with anesthetic gases.
	Versatility: good in airway surgery.	Intermittent end-tidal CO_2 monitoring.
		High gas flow required.
		Need for humidification.

Weaning from a Ventilator

The initiation of spontaneous ventilation after controlled ventilation can be hastened by:

I. Decreasing the frequency of controlled ventilation
II. Decreasing anesthetic depth
III. Antagonism of sedative/analgesic drugs and neuromuscular blockade
IV. Physical manipulation: rolling the patient, twisting an ear, pinching a toe
V. Respiratory stimulants: doxapram administration, 0.2 to 0.5 mg/kg intravenously

Preventing Hazards (see box)

I. Always be prepared to convert the anesthesia system back to the nonventilator mode in case of unforeseen ventilator problems; keep the rebreathing bag near the ventilator
   A. Venous return, cardiac output, and arterial blood pressure are decreased in animals that attempt to spontaneously breathe when a mechanical ventilator cycles into the inspiratory phase: called "bucking" the ventilator

II. Verify proper ventilator function before use
- A. Verify that all controls are operational
- B. Perform a leak test independent of that performed for the breathing circuit
  1. Ascending bellows: fill bellows using O_2 flush valve on the anesthesia machine; occlude ventilator delivery hose; bellows will remain in fully ascended position if no leaks are present
  2. Descending bellows: fully empty bellows; occlude ventilator delivery hose; bellows will remain fully contracted if no leaks are present

Complications Associated with Mechanical Ventilation

Decreased venous return, cardiac output, arterial blood pressure
Ventilator-induced lung injury
Ventilator-associated pneumonia
Pneumothorax; pneumomediastinum
Patient-ventilator asynchrony
Endotracheal tube occlusion and accidental disconnection
Tracheal necrosis

Respiratory Assist Devices

I. Manual resuscitators
- A. Self-inflating bags (e.g., Ambu) and one nonrebreathing valve
- B. Useful for rapid emergency ventilation with room air or supplemental O_2

II. Demand Valves (see Fig. 22-6)
- A. An apparatus that can be inserted into the proximal end of an endotracheal tube that can deliver O_2 on demand from a patient-initiated breath or from operator assistance
  1. Inspiration is passive or assisted
  2. Expiration is passive
  3. Adapters are available for large- and small-animal use
  4. Can generate an inspiratory flow sufficient for a 450 kg horse if connected to a line pressure of at least 50 psi.

Monitoring During Anesthesia

14

"You see only what you look for, you recognize only what you know."
MERRIL C. SOSMAN
"Diligence is the mother of good fortune."
MIGUEL DE CERVANTES

OVERVIEW

A variety of monitoring equipment is available for determining an animal's status during anesthesia. The electrocardiogram (ECG), the electroencephalogram, and the electromyogram can be displayed and recorded. Blood pressure (arterial [ABP] or central venous [CVP]), heart sounds and/or peripheral blood flow, arterial and venous pH, lactate, oxygen (O_2) and carbon dioxide (CO_2) tensions, and arterial or capillary blood O_2 saturation (pulse oximetry [SpO_2]) can be determined. End-expired samples of respiratory gases can be analyzed for O_2/CO_2 and inhalant anesthetic concentration. "Point of care" devices are available that permit animal-side evaluation of the hemogram, acid-base values, blood chemistries, and serum enzyme values within minutes of collecting a peripheral blood sample. All the monitoring equipment in the world, however, cannot replace an educated, attentive anesthetist.

General Considerations

I. The animal's ability to compensate for anesthetic induced changes are generally depressed by anesthesia

II. Perioperative monitoring is a sentinel for abnormal or deteriorating physiology and improves safety during anesthesia:
- A. Frequent monitoring of physiologic variables facilitates informed and timely responses to changes in the animal's status
- B. The completion of an anesthetic record provides method to objectively trend changes and a database for comparison with subsequent anesthetic procedures

III. Prerequisites for helpful intraoperative monitoring: A trained vigilant anesthetist is the most important. This means:
- A. Applied understanding of normal physiology and pathophysiology

B. Thorough, accurate knowledge of the animal's history and physiologic status
C. Knowledge of the pharmacology, pharmacokinetics, pharmacodynamics, and toxicity of anesthetic drugs and perioperative therapies
D. Availability of a convenient system for recording observations (anesthetic record)
E. A thorough knowledge of the monitoring devices, their operation and limitations, and the inherent assumptions associated with their use

Basic Principles

I. Monitor body functions (see Chapter 2 for normal values)
A. Formulate a monitoring plan based on the following:
1. Animal's health status and disease(s)
2. Specific procedure to be performed
3. Anesthetic drugs and techniques selected
4. Available monitoring equipment
5. Anticipated duration of anesthesia
B. Intraoperative decisions are based on comparisons with normal values (i.e., Are observed responses to anesthesia qualitatively and/or quantitatively appropriate? Are measured variables within normal limits?)

II. Monitor more than one body system and more than one variable per body system, when possible
A. Evaluating several indices over time (e.g., heart rate, respiratory rate) rather than fragments of information increases the likelihood of detecting abnormal responses to anesthesia
B. Determining trends in individual variables facilitates an early diagnosis and response

III. Use monitoring techniques that are specific, accurate, and complementary
A. Use simple, reliable techniques (e.g., visual inspection, palpation, auscultation)
B. Check instrument calibrations frequently; inaccurate information can be confusing, misleading, and dangerous
C. Never depend solely on one piece of monitored information

Noninvasive Monitoring Techniques

I. Information is gathered by observing readily apparent variables (e.g., rate of volume of breathing) and/or employing diagnostic

testing (e.g., ECG; pulse oximeter; ABP; capnometry ($ETCO_2$]; transcutaneous (O_2, CO_2) that does not invade the body

A. Advantages
   1. Devices are generally easy to use, reasonably reliable, and can be used to determine trends or changes in the monitored variable
   2. Animal is not at risk for complications caused by the monitoring technique

B. Disadvantages
   1. Not all physiologic variables (e.g., pH and blood gases, electrolytes, lactate) can be accurately monitored noninvasively
   2. Inaccurate (highly variable) information is sometimes gathered when a noninvasive technique (e.g., noninvasive ABP) is substituted for a more invasive procedure (e.g., arterial catheterization) to determine the same information

Invasive Monitoring Technique

I. Information is gathered by placing instruments within the body (e.g., intravascular pressure catheters, tissue oximetry, temperature)

A. Advantages
   1. Data is less influenced by confounding factors
   2. Many accurate, reliable, and simple monitoring techniques are available
   3. A direct measurement of a physiologic variable is often provided with fewer assumptions

B. Disadvantages
   1. Greater risk of complications, including the following:
      a. Trauma
      b. Infection
      c. Hemorrhage
      d. Alterations in normal organ or tissue function (e.g., cardiac dysrhythmias)
   2. Some monitoring techniques require advanced technical knowledge and skills (EEG interpretation; respiratory pressure-volume loops)

Physiologic Considerations

I. Homeostasis

A. Monitoring responses to anesthesia and surgical stimulation (Boxes 14-1 and 14-2)

BOX 14-1

American College of Veterinary Anesthesiologists Suggestions For Monitoring

Circulation

Objective: to ensure that blood flow to tissues is adequate

Methods:

1. Palpation of peripheral pulse
2. Palpation of heartbeat through chest wall
3. Auscultation of heartbeat (stethoscope, esophageal stethoscope, or other audible heart monitor)
4. Electrocardiogram (continuous display)
5. Noninvasive blood flow or blood pressure monitor (e.g., Doppler ultrasonic flow detector, oscillometric flow detector)
6. Invasive blood pressure monitor (arterial catheter connected to transducer/oscilloscope or to aneroid manometer)

Oxygenation

Objective: to ensure adequate oxygen (O_2) concentration in the animal's arterial blood

Methods:

1. Observation of mucous membrane color
2. Pulse oximetry (noninvasive estimation of hemoglobin saturation)
3. O_2 analyzer in the inspiratory limb of the breathing circuit
4. Transcutaneous tissue PO_2
5. Blood gas analysis (PaO_2)
6. Co-oximetry (direct measurement of hemoglobin saturation in the blood)

Ventilation

Objective: to ensure that the animal's ventilation is adequately maintained

Methods:

1. Observation of chest wall movement
2. Observation of breathing bag movement
3. Auscultation of breath sounds
4. Audible respiratory monitor
5. Respirometry (measurement of tidal volume ± minute volume)
6. Capnography (measurement of CO_2 in end-expired gas)
7. Buccal and transcutaneous CO_2
7. Blood gas monitoring ($PaCO_2$)

Anesthetic record

Objective: to maintain a legal record of significant events and to enhance recognition of trends in monitored parameters

Methods:

1. Record all drugs administered to each animal, noting the dose, time, and route of administration
2. Record monitored parameters (minimum: heart rate, respiratory rate) on a regular basis (minimum: every 5 min) during anesthesia

Personnel

Objective: to ensure that a responsible individual is aware of the animal's status at all times during anesthesia and recovery and is prepared either to intervene when indicated or to alert the veterinarian in charge about changes in the animal's condition

BOX 14-1

American College of Veterinary Anesthesiologists Suggestions For Monitoring—cont'd

Methods:

1. If a veterinarian, technician, or other responsible person is unable to remain with the animal continuously, a responsible person should check the animal's status on a regular basis (at least every 5 min) during anesthesia and recovery
2. A responsible person may be present in the same room, although not necessarily solely occupied with the anesthetized animal (for instance, the surgeon may also be responsible for overseeing anesthesia)
3. In either of the above situations, audible heart and respiratory monitors are suggested
4. A responsible person, solely dedicated to managing and caring for the anesthetized animal during anesthesia, remains with the animal continuously until the end of the anesthetic period

BOX 14-2

Commonly Monitored Parameters and Potential Causes of Abnormal Responses

Respiratory rate and pattern

Tachypnea: Too "light," pain, hypoxemia, hypercarbia, hyperthermia, true or paradoxical CSF acidosis, drug effects (e.g., doxapram)

Apnea: Too "deep," hypothermia, recent hyperventilation (especially while breathing oxygen-enriched gases), musculoskeletal paralysis (pathologic or pharmacologic), drug effects (e.g., ketamine, thiobarbiturates, propofol)

Heart rate

Tachycardia: Too "light," pain, hypotension, hypoxemia, hypercarbia, ischemia, acute anaphylactoid reactions, anemia, drug effects (e.g., thiobarbiturates, ketamine, catecholamines), fever, hypokalemia

Bradycardia: Too "deep," hypertension, elevated intracranial pressure, surgically induced vagal reflexes (e.g., visceral stretch responses), hypothermia, hyperkalemia, myocardial ischemia/anoxia, drug effects (e.g., xylazine, narcotics)

Arterial blood pressure

Hypertension: Too "light," pain, hypercarbia, fever, drug effects (e.g., catecholamines, ketamine)

Hypotension: Too "deep," relative or absolute hypovolemia, sepsis, shock, drug effects (e.g., thiobarbiturate boluses, inhalant anesthetics)

Corneal reflexes*

Hyperactive: Too "light," pain, hypotension, hypoxemia, hypercarbia, drug effects (e.g., ketamine)

Hypoactive: Too "deep," CNS depression (e.g., excessively deep anesthesia, acidosis, hypotension)

*Pertains to horses and ruminants only; not useful in pigs, dogs, and cats.
CSF, Cerebral spinal fluid; *CNS*, central nervous system.

II. Monitoring key organ systems: Classic monitoring signs were described in terms of stages and planes of anesthesia. These classic signs use eye position and reaction, muscle relaxation, respiratory rate and pattern, and response to surgical stimulation to determine anesthetic depth (see Fig. 9-1). The signs of anesthesia were developed based on diethyl ether anesthesia but continue to be useful for describing the depressant qualities of anesthesia.

A. Central nervous system (CNS)

1. Observe reflex activity to monitor degree of CNS depression
   a. Eye reflexes: Generally more useful and discriminative in large animals
      (1) Palpebral: brisk if too light, absent in many animals, and when the animal is in a surgical plane of anesthesia
      (2) Corneal: lightly touch the cornea with gauze or cotton. Present until the animal is deeply anesthetized.
      (3) Nystagmus: present during light planes of anesthesia
      (4) Lacrimation: often present with nystagmus, indicating light plane of anesthesia
   b. Jaw tone: an indication of overall muscle relaxation. Moderate resistance to fully opening the mouth is present during a moderate surgical plane of anesthesia. More useful in small animals.
   c. Anal reflex: dull to absent during a surgical plane of anesthesia (species dependent)
   d. Pedal reflex: absent with toe pinch during a surgical plane of anesthesia. Withdrawal indicates a light stage of anesthetic that is likely to be inadequate to perform surgery.
2. Monitor skeletal muscle tone and degree of relaxation
3. Electroencephalography
   a. Records and averages brain activity
   b. Correlates to depth of anesthesia
      (1) The bispectral index (BIS) can be used to monitor anesthesia (Fig. 14-1)
      (2) Consciousness is represented by a BIS value of 100. Lower values indicate greater degrees of CNS depression (Fig. 14-2, *B*)



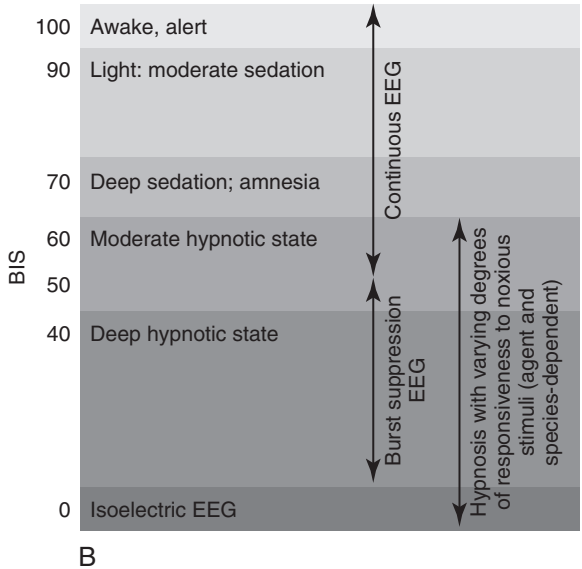


FIG. 14-1. The bispectral index (BIS = 52) determines the level of consciousness by algorithmic analysis of an animal's electroencephalogram during general anesthesia (A). This monitor is a reasonable guide to anesthetic depth in dogs and cats (B).

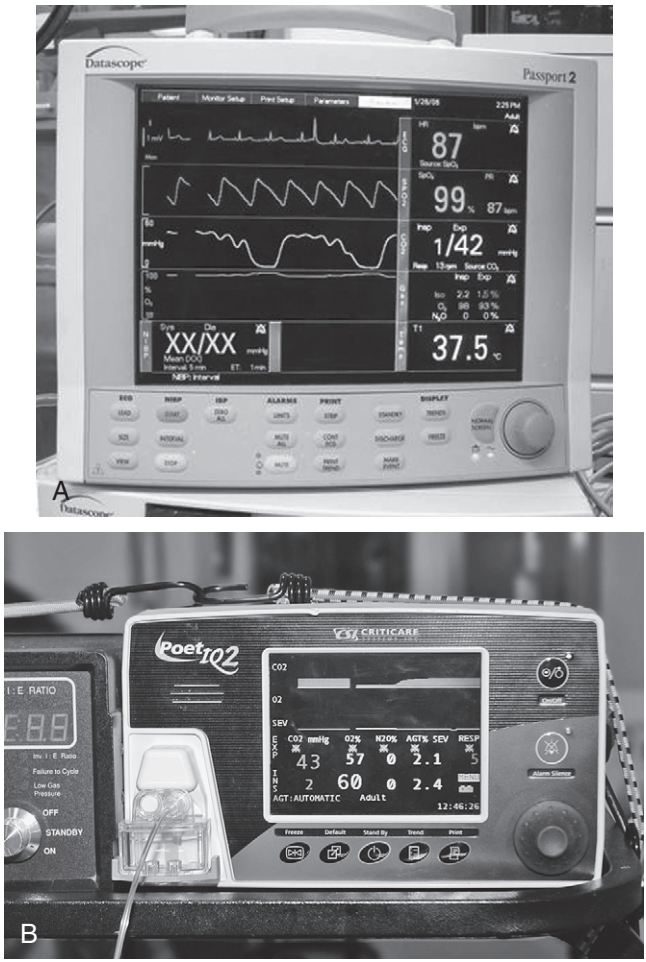


FIG. 14-2. A, Multiparameter monitors display heart rate (87) and rhythm (sinus with artifact)) plethysmographic pulse rate (87) and SpO_2 (99), expired CO_2 ($ETCO_2$ = 42) and anesthetic circuit (ET-Iso = 2.2) concentrations, and body temperature (37.5°C). Some multiparameter monitors (B) display expired CO_2 ($ETCO_2$ = 43), inspired O_2 concentration (60%), and the expired anesthetic concentration of sevoflurane (ET-SEV = 2.1).

4. End-tidal concentration of anesthetic gases can be monitored, correlated to anesthetic depth, and compared to known MAC values for a particular inhalant anesthetic (see Fig. 14-2, *A*, and *B*)

B. Ventilation and the respiratory system (see Boxes 14-1 and 14-2; Figs. 14-3 through 14-8)

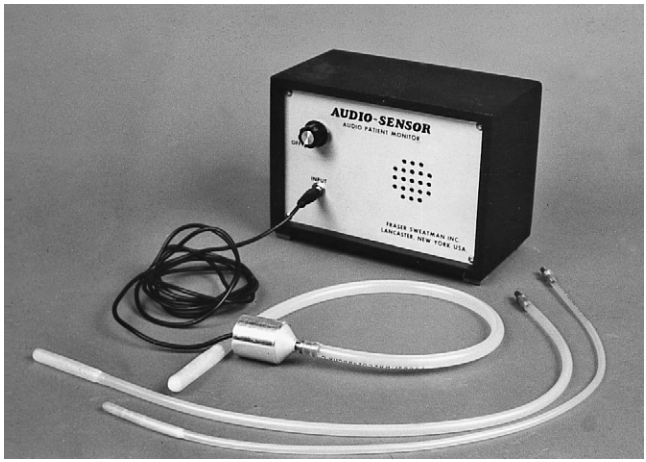


FIG. 14-3. Heart and respiratory sounds can be broadcast from a speaker and rates can be determined.



FIG. 14-4. Airway temperature sensing devices can detect warm exhaled gas and broadcast a "beep" when the animal exhales.

1. Noninvasive measurements
   a. Respiratory frequency
   b. Respiratory pattern
      (1) Irregular patterns suggest respiratory depression or alterations in CNS regulation of breathing (e.g., ketamine and apneustic breathing)
   c. Changes in tidal volume, noted by observing thorax and rebreathing bag
      (1) Rapid shallow breathing suggests hypoxemia, hyperthermia, respiratory disease

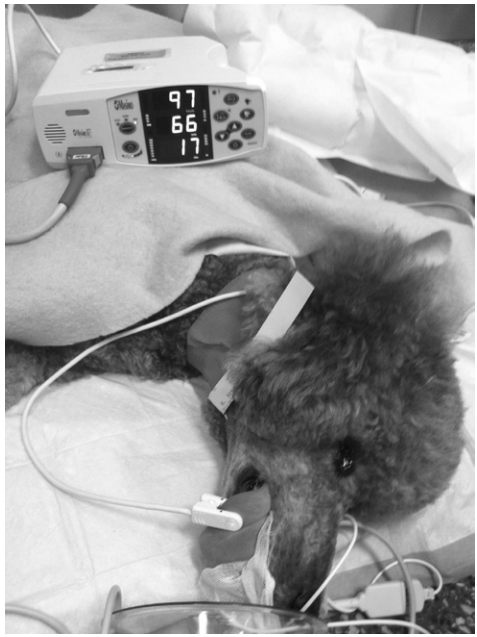


FIG. 14-5. Noninvasive acoustic respiratory rate monitors can be combined with pulse oximeters to determine SpO_2 (94), heart rate (66) and respiratory rate (16). This type of monitor is provides clinically valuable information for animals recovering from anesthesia.

2. Noninvasive equipment
   a. Esophageal or precordial stethoscope (useful to count respiratory and heart rate; see Fig. 14-3)
   b. Breathing frequency and pressure monitors (see Figs. 14-4 through 14-6)
      (1) Frequency monitors are activated by changes in airway temperature or gas flow; some emit an audible tone and digitally display respiratory rate; some contain alarms indicating apnea
      (2) Positive-negative pressure gauges (P-N gauges) indicate the anesthetic circuit pressure and are used to indicate (monitor) circuit (lung) pressure during manual or mechanical ventilation
   c. Capnometry: Analysis of inspired and expired CO_2 concentration (Figs. 14-2, 14-6 through 14-9): typically sampled at the connection of the endotracheal tube to the breathing circuit (Y-piece). Sample is analyzed by a CO_2 sensor at the connection (mainstream; see Fig. 14-7) or expired gas is continuously aspirated via

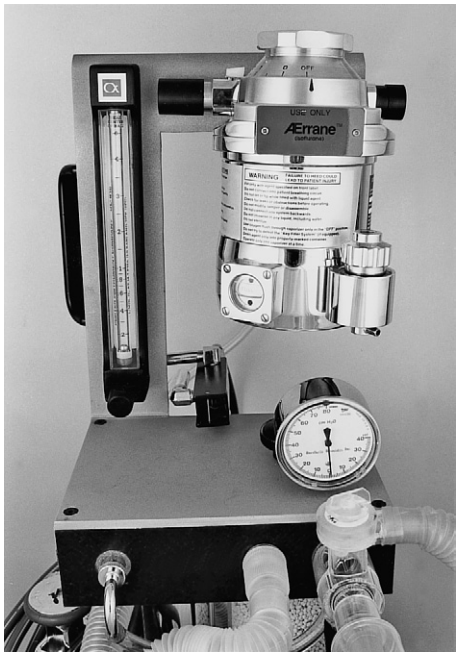


FIG. 14-6. Respiratory monitors used in anesthesia practice. The positive-negative pressure gauge (lower right) is used to monitor anesthetic breathing circuit pressure.

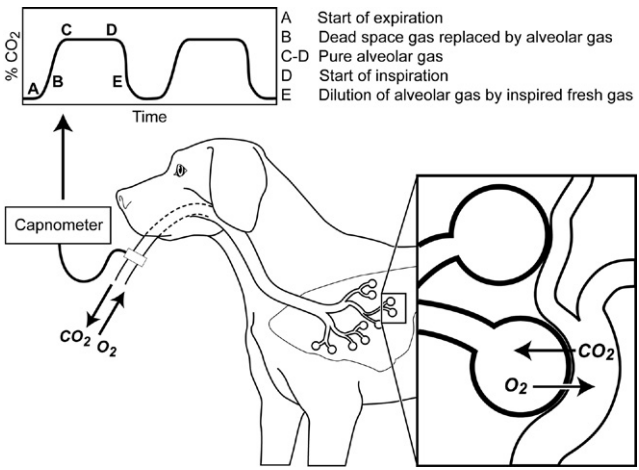


FIG. 14-7. End-tidal carbon dioxide ($ETCO_2$) monitoring: the amount of carbon dioxide (CO_2) in the expired gas increases during exhalation (A) and is determined to assess the adequacy of breathing (goes up during hypoventilation). The increases and decreases in the end-tidal concentration of CO_2 during expiration and inhalation, respectively, produce a characteristic capnogram (upper inset). Portable hand-held capnometers are available (see Fig. 14-9).

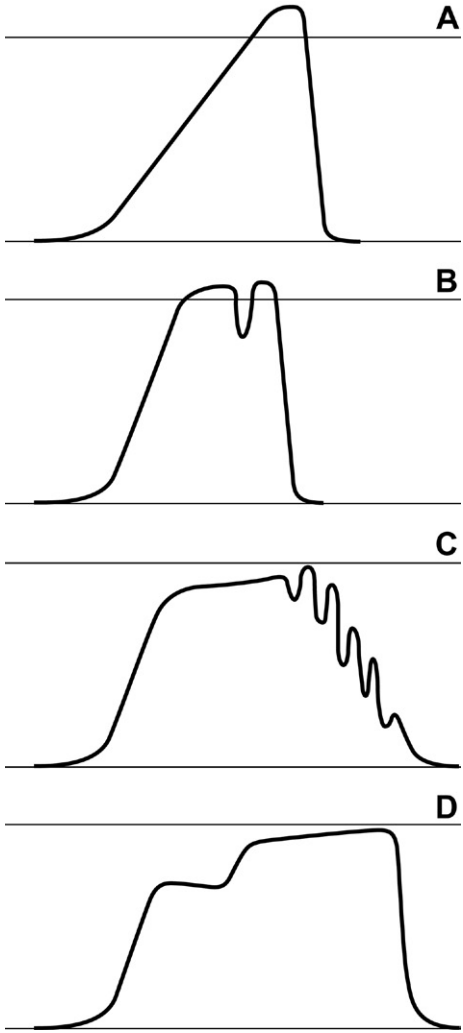


FIG. 14-8. Analysis of the capnogram can be used to identify airway obstruction (A), diaphragmatic twitches (B), cardiac oscillations (C), and delayed or uneven emptying of the lungs (D).

small-diameter tube and analyzed within the monitor. Sidestream analyzers require a waste gas scavenger to eliminate the aspirate. The highest (end tidal) and lowest (inspired) concentrations of CO_2 and the respiratory rate are digitally on the monitor. A graphic waveform of the CO_2 concentration during each



FIG. 14-9. Portable, end-tidal CO_2 ($ETCO_2$) monitors facilitate the determination of $ETCO_2$ and respiratory rate. Some provide a visual display of the CO_2 concentration (capnogram).

respiratory cycle is displayed (capnogram, capnography) (see Figs. 14-2, *A*, 14-9).

(1) End-tidal carbon dioxide ($PETCO_2$) concentrations are indicative of arteriolar concentrations of CO_2 ($PaCO_2$)
(2) Used to determine adequacy of ventilation
(3) Used to monitor the adequacy of ventilation during controlled ventilation
(4) Arterial CO_2 ($PaCO_2$) concentrations are underestimated by 3 to 5 mm Hg in dogs
(5) Measurements become more inaccurate during hypoventilation, ventilation/perfusion



FIG. 14-10. A ventilometer (respirometer) quantitates tidal volume and minute volume.

ratio mismatch, or during abnormal breathing patterns

d. Spirometry (Fig. 14-10): measures the volume of a single breath or minute ventilation. Typically inserted between the breathing hose and expiratory unidirectional valve of the circle breathing system

3. Invasive measurements
   a. Arterial and/or venous blood gas, pH, and lactate analysis (Fig. 14-11, *A*, and *B*) (see Chapter 15)

C. Oxygenation
1. Pulse oximetry (Fig. 14-12): A monitoring method that indirectly determines the percentage O_2 saturation of blood hemoglobin (Hb; as opposed to measuring O_2 saturation directly via a blood sample [oximetry]) and changes in skin blood volume, producing a photoplethysmograph; most pulse oximeters also display the heart rate
   a. Estimates percentage saturation of O_2 in arterial blood (SpO_2)
   b. A spectrophotoelectric device applied directly to nonhaired skin over a pulsating vascular bed; light absorbance of oxygenated versus reduced hemoglobin detected and the percentage of oxygenated hemoglobin is displayed numerically
      (1) Inaccurate in the presence of carboxyhemoglobin or methemoglobin; some pulse oximeters display

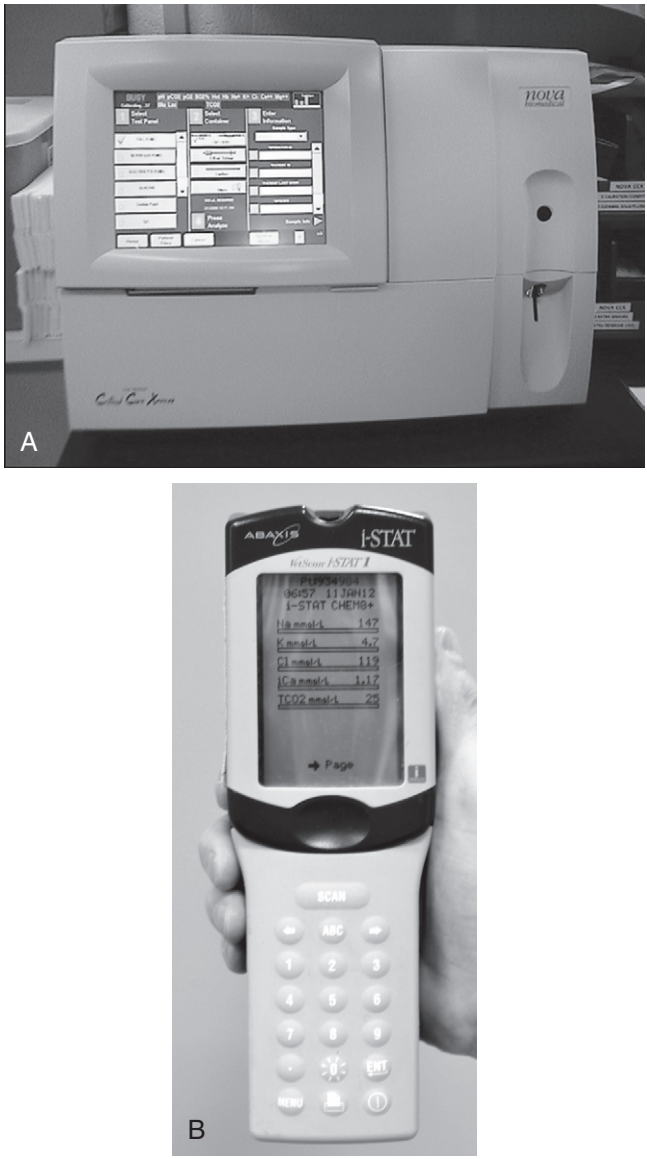


FIG. 14-11. Self-calibrating multiparameter blood gas machines (A) provide the ability to obtain a complete acid-base profile (pH, PO_2, PCO_2, HCO^-, BE, lactate, Na^+, Cl^-, K^+, etc). Hand-held blood chemical analyzers (B) are also available and provide most of the same functions.



FIG. 14-12. Advanced pulse oximeters (Masimo Rad-7) noninvasively monitor arterial blood O_2 saturation (SpO_2), total hemoglobin concentration (SpHb), methemoglobin (SpMet), carboxyhemoglobin (SpCO), O_2 content (SpOC), plethysmographic pulse wave variability index (PVI = an index of fluid responsiveness), and heart rate.

percentage oxygenated Hb, carboxyhemoglobin (COHb), methemoglobin (MetHb), and fetal hemoglobin (FeHb; see Fig. 14-12)

(2) The pulsatile signal is reduced by hypotension, hypothermia, and vasoconstriction, which limits SpO_2 determination

c. Sites for attachment of probes
   (1) Tongue
   (2) Symphysis of mandible
   (3) Toe web
   (4) Digit
   (5) Esophagus
   (6) Rectum (reflectance probe)
   (7) Superficial artery
   (8) Prepuce
   (9) Vulva
   (10) Scrotum
   (11) Pinna
   (12) Base of the Tail

2. Oximetry: Hb O_2 saturation (SaO2) obtained from an arterial or venous blood sample; abnormal Hb types determined from a blood sample
3. O_2 analyzers: analysis of inspired O_2 concentration

D. Cardiovascular system (see Boxes 14-1 and 14-2)
1. Heart rate
   a. Range of normal heart rates, by species (beats/minute) (see Chapter 2)
      (1) Dog: 70 to 100
      (2) Cat: 100 to 200

(3) Horse: 30 to 45; up to 80 in foals
(4) Cow: 60 to 80
(5) Sheep, goat: 60 to 90
(6) Pig: 60 to 90
(7) Llama: 50 to 100

b. Limits of heart rate during anesthesia in beats/minute (values outside these limits indicate that cardiovascular function may be impaired)
(1) Dog: less than 50, more than160
(2) Cat: less than 100, more than 200
(3) Horse: less than 28, more than 50
(4) Cow: less than 48, more than 90
(5) Sheep, goat: less than 60, more than 150
(6) Pig: less than 50, more than 150
(7) Llama: less than 50, more than 150

c. Techniques for monitoring heart rate
(1) Palpation of arteries or the heart
(a) Dog: femoral, dorsal pedal, digital, and lingual arteries; precordium
(b) Cat: femoral artery, precordium
(c) Cow, sheep, and goat: auricular, digital, coccygeal, and dorsal metatarsal arteries
(d) Horse: facial, transverse facial, dorsal metatarsal, and palatine arteries
(e) Pig: femoral and auricular arteries
(f) Llama: auricular and femoral arteries
(2) Indirect method uses esophageal stethoscope (see Fig. 14-3)
(a) Coupled to earpieces or to an electronic amplifier
(b) Advantages: inexpensive; can detect abnormalities in rhythm and rate; can monitor breath sounds
(c) Disadvantages: difficult when sounds are muffled or when surgery involves the mouth or throat

d. Peripheral pulse amplifiers
(1) Positioned over peripheral arteries; audible beep heard with each pulse
(2) Advantages: can determine heart rate and rhythm
(3) Disadvantages: prone to electrical interference; difficult to keep in place

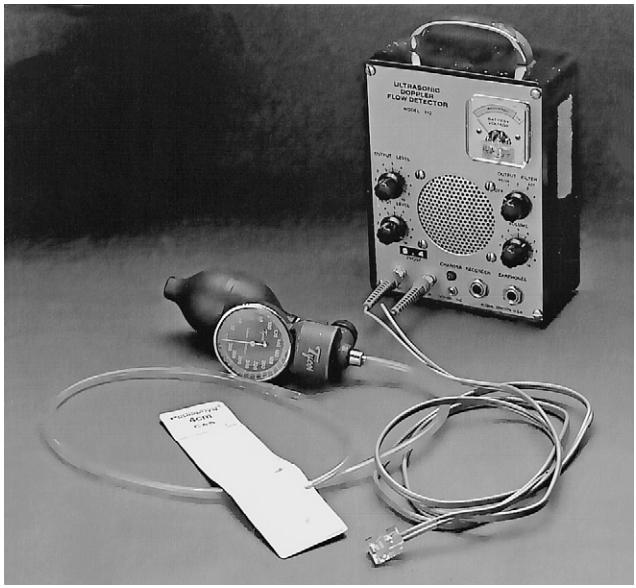


FIG. 14-13. Electronically activated crystals emit nigh frequency waves that can be used to determine blood flow (Doppler shift). Blood flow can be audibly broadcast and blood pressure monitored with a sphygmomanometer.

e. Ultrasonic Doppler device (Fig. 14-13)
   (1) Doppler crystal applied over peripheral artery (e.g., palmar artery); sound of blood flow is audible
   (2) Advantages: detects abnormalities in heart rate and rhythm; can also be used to estimate systolic blood pressure (BP); reliable once signal is acquired
   (3) Systolic BP value obtained with a Doppler device is close to the mean ABP obtained by a catheter placed in a peripheral artery
   (4) Disadvantages: accurate for systolic BP only if appropriate cuff size is used, rate is not displayed

f. ECG, hand-held monitors are available (Fig. 14-14)
   (1) Direct visualization of ECG, or sound amplifier that beeps with each R wave
   (2) Advantages: size, portability, and point-of-care visualization of ECG allows interpretation of heart rate and rhythm
   (3) Disadvantages: ECG activity can continue to look normal in the absence of a perfusing BP (pulseless electrical activity)



FIG. 14-14. Hand-held (point of care) electrocardiogram (ECG) monitors are useful for determining rapid heart rate and rhythm.

g. Pulse oximeters
   (1) Most units display heart rate digitally
h. Reasons for abnormal heart rates (see Box 14-2)
   (1) Bradycardia
      (a) Drugs: opioids, α_2-agonists (e.g., xylazine, medetomidine, dexmedetomidine, detomidine, romifidine), anticholinesterases (e.g., neostigmine)
      (b) Excessive anesthetic depth
      (c) Hyperkalemia
      (d) Preexisting heart disease (second- or third-degree heart block)
      (e) Vagal reflex (intubation, oculocardiac reflex)
      (f) Terminal stages of hypoxemia
      (g) Hypothermia
   (2) Tachycardia
      (a) Drugs: anticholinergics, ketamine, pancuronium, sympathomimetics, thiobarbiturates
      (b) Hypokalemia
      (c) Hyperthermia
      (d) Inadequate anesthetic depth
      (e) Pain
      (f) Hypercarbia and hypoxemia
      (g) Anemia, hypovolemia

(h) Hyperthyroidism, pheochromocytoma
(i) Anaphylaxis

2. Peripheral perfusion
   a. A function of ABP and local vasomotor tone
   b. Assessment
      (1) Capillary refill time
         (a) Normal: less than 1 to 2 seconds
         (b) Assess on oral or vulvar mucous membranes
      (2) Peripheral pulse strength
         (a) Pulse pressure (systolic minus diastolic)
         (b) May be weak or rapid and weak during hypotension or vasodilation
      (3) Urine production
         (a) Palpation of bladder
         (b) Urinary catheterization
         (c) Dog and cat: 0.5 to 2 mL/kg of body weight/hour
3. Central venous pressure (CVP) is obtained by advancing a venous catheter into the right atrium and measuring the mean right atrial pressure; monitoring acute changes in CVP can help determine the animal's responsiveness to fluid therapy and to detect fluid overload (Fig. 14-15)
   a. Physiologic significance
      (1) Right atrial pressure is a balance between:
         (a) Cardiac output: the forward flow of blood
         (b) Venous return: tendency for blood to flow from the peripheral veins back into the right atrium
   b. Range of normal values
      (1) 0 to 4 cm H_2O: standing, awake animals
      (2) 2 to 7 cm H_2O: anesthetized small animals
      (3) 15 to 25 cm H_2O: anesthetized large animals
   c. Indications
      (1) Monitoring responsiveness fluid therapy
      (2) Assessing cardiac output

NOTE: CVP is not always an accurate indicator of fluid responsiveness or fluid overload.

(a) Shock (CVP falls)
(b) Heart failure (CVP rises)
(c) Anesthesia (CVP rises)

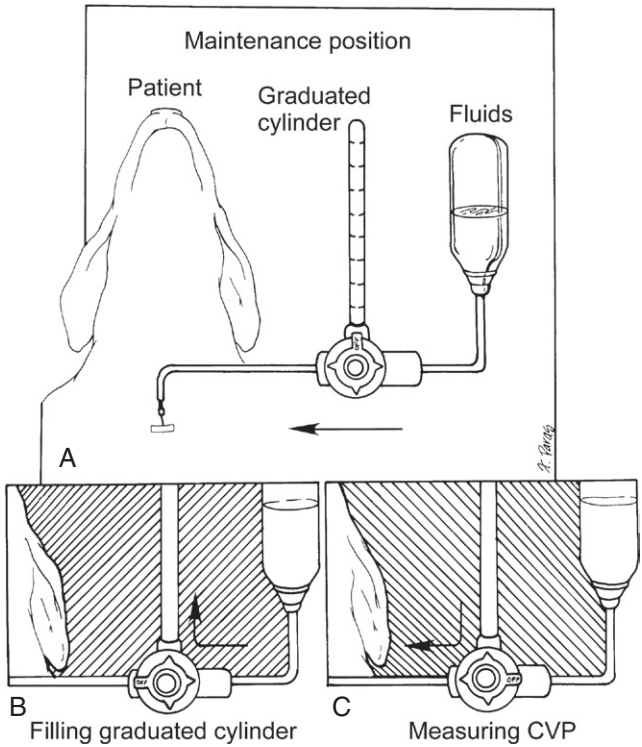


FIG. 14-15. A, Central venous blood pressure (CVP) monitoring. **B,** A graduated cylinder filled with saline solution is positioned such that the three-way stopcock is at or below the level of the heart. **C,** The cylinder is opened to the animal so that the fluid in the graduated cylinder equilibrates with the pressure in the right atrium.

d. Primary factors affecting CVP
   (1) Blood volume
      (a) Increase in circulating blood volume may cause an increase in CVP
      (b) Decrease in effective circulating blood volume may cause a decrease in CVP; acute hemorrhage
   (2) Vascular tone
      (a) Venous dilation (e.g., acepromazine) may cause CVP to decrease because of peripheral pooling of blood and decreased venous return
      (b) α_2-Agonists produce venous constriction and an increase in CVP
   (3) Cardiac contractility

(a) Decreases in cardiac contractile force cause CVP to increase because of the decreased contractile force of the heart

(4) Heart rate

(a) May decrease CVP with onset of tachycardia or increase CVP with onset of bradycardia

(5) External cardiac factors

(a) Intrathoracic pressure: elevations in intrathoracic pressure (positive pressure ventilation) increase CVP; decreases in intrathoracic pressure decrease CVP

(b) Intrapericardial pressure increases CVP

- Cardiac tamponade
- Congenital pericardial herniation
- Ventricular filling is decreased or eliminated

(c) Body position: primarily an issue in large-animal species because of hydrostatic pressure (CVP may increase 10 to 15 cm H_2O when a horse is positioned in lateral recumbency)

e. Clinical approach to low CVP

(1) Increase blood volume

(2) Animals with relative or absolute hypovolemia should receive appropriate intravenous (IV) fluids (crystalloids, blood, colloids) until the CVP approaches the upper limit of normal range

f. Clinical approach to elevated CVP

(1) Generally indicates hypervolemia or myocardial depression (right heart failure)

(a) Decrease or stop IV fluid administration

(b) Administer drugs to improve cardiac function (dopamine, dobutamine)

g. Hazards of CVP measurement

(1) Air embolism

(2) Thrombophlebitis

(3) Hemorrhage

h. Equipment

(1) IV catheter of sufficient length to reach the great veins in the chest (preferably the right atrium)

(2) CVP manometer (Fig. 14-16)

(a) Homemade

1. Three-way stopcock

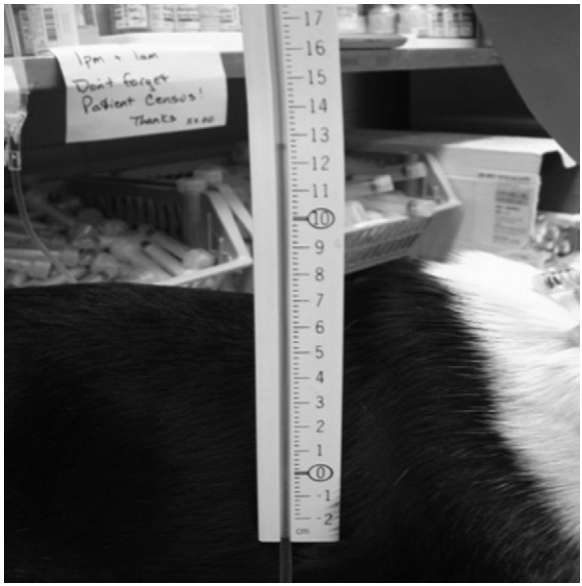


FIG. 14-16. Elevated central venous blood pressure (CVP ≈ 13 cm H_2O) in a dog with right heart failure. Note the zero pressure point is considered the base of the heart.

2. Graduated cylinder or pipette
3. Connecting tubes

i. Procedure (see Fig. 14-16)

(1) Suspend the graduated cylinder or pipette so that the three-way stopcock is below the animal's heart base; draw an imaginary line parallel to the floor between the animal's heart base and the cylinder; this marks the point of zero pressure on the cylinder

(a) The heart base is marked by the sternum when the animal is in lateral recumbency

(b) The heart base is marked by the point of the shoulder when the animal is standing or in dorsal recumbency

4. ABP

a. Noninvasive

NOTE: Occluding cuffs should be one half the circumference of the extremity around which they are placed.

(1) Oscillometric method (Figs. 14-17 and 14-18)
   (a) An air-filled occlusion cuff is placed around a peripheral limb (small animal, foal) or at the base of the tail (small animal, large animal); air is gradually released from the cuff until arterial



FIG. 14-17. Arterial blood pressure (ABP) can be determined noninvasively by devices that detect peripheral artery pulsations or oscillations (oscillometric technique).



FIG. 14-18. Portable and versatile oscillometric arterial blood pressure (ABP) measuring devices (PetMAP) combine a visual display with the sphygmomanometer.

pulsations (oscillations) are detected and electronically displayed
(b) Advantages: easy to use; determines heart rate and systolic, mean, and diastolic BP
(c) Disadvantages: may not be absolutely accurate but should accurately reflect trends; accuracy depends on occluding cuff size; inaccurate at low BPs

(2) Ultrasonic Doppler method (see Fig. 14-13)
(a) Doppler crystal placed over peripheral artery (e.g., dog: digital, dorsal pedal; horse: coccygeal)
(b) Place appropriately sized inflatable cuff with pressure gauge proximal to Doppler crystal; inflate cuff until audible blood flow sounds stop, then slowly deflate until pulse is first heard; this corresponds to the systolic BP as displayed on the pressure gauge
(c) Advantages: pulse rate and rhythm can be determined
(d) Disadvantages: accuracy depends on cuff size, which should be one half the limb circumference; measures systolic pressure only; inaccurate at low BPs

b. Invasive methods for determining arterial BP
(1) Invasive arterial pressure monitoring provides an accurate quantitative means for determining ABP; BP is not an indicator of cardiac output (CO) (Fig. 14-19)
(a) Monitoring of hemodynamic effects of anesthetic drugs, fluid therapy and vasoactive drug (e.g., dopamine) administration

(2) Hazards of invasive arterial pressure monitoring
(a) Hemorrhage and/or hematoma
(b) Air embolization
(c) Arterial thrombosis and vessel occlusion (rare)
(d) Infection (rare)
(e) Formation of atrioventricular fistula or aneurysm (rare)

(3) Equipment
(a) Intraarterial catheter with three-way stopcock
(b) Pressure-sensing device (e.g., pressure transducer and oscilloscope, mercury manometer)



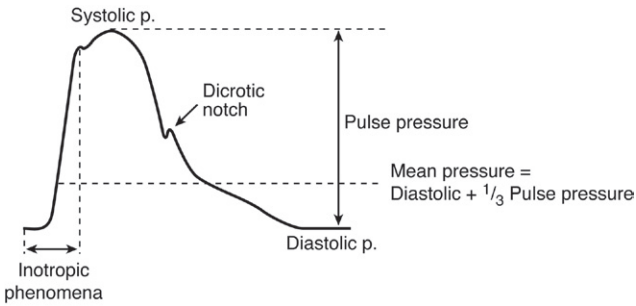


FIG. 14-19. A catheter can be inserted into the dorsal pedal artery of the dog (A) to directly record arterial blood pressure (ABP). The dorsal pedal artery of a dog is catheterized (top left & right figures). The catheter is secured with tape and is connected to a pressure transducer and then to a multiparameter monitor (lower figures). Key aspects of the arterial pressure waveform (B).

(4) Procedure (see Fig. 14-19)
   (a) Cannulate a peripheral artery (e.g., dorsal pedal artery in dogs; coccygeal artery in cats; facial artery in horses) aseptically with the arterial catheter (see Fig. 1-3)
   (b) Flush the catheter with heparinized saline solution; always aspirate first to prevent air embolism
   (c) Attach the pressure transducer while stopcock is closed to the artery
   (d) Open the transducer to air to establish the baseline (zero) reference pressure with the transducer at the level of the right atrium

(e) Open the arterial line to the pressure transducer; pulse-pressure curve should be displayed at this point
(f) After removing the arterial catheter, place manual pressure on the site of cannulation for 5 minutes to prevent hematoma formation

c. Physiologic significance
(1) ABP is expressed clinically in millimeters of mercury (mm Hg) with the zero reference at the level of the right atrium
(2) The mean pressure required to adequately perfuse organs is approximately 60 mm Hg; the systolic blood pressure should be greater than 80 mm Hg
(3) Normal arterial pressure values
- Systolic: 110 to 160 mm Hg
- Diastolic: 50 to 70 mm Hg
- Mean: 60 to 90 mm Hg
- Systolic – diastolic = pulse pressure

(4) Components of the pulse pressure
(5) Inotropic component: the steep ascending limb of the pressure pulse

d. Primary factors affecting the ABP
(1) ABP = CO × total peripheral resistance (TPR)

ABP = CO × TPR; CO = stroke volume (SV) × heart rate (HR).
Therefore: ABP = SV × HR × TPR

(a) Factors increasing SV or CO favor an increase in arterial pressure
(b) Factors increasing TPR favor an increase in arterial pressure

---

NOTE: Decreases in HR, SV, or TPR individually or in any combination can decrease ABP.

---

(2) Pulse pressure curves

e. Clinical value of arterial pressure monitoring
(1) Maintain adequate tissue perfusion pressure (MAP >60 mm Hg)
(2) Determine the effects of anesthesia on cardiac output and/or peripheral resistance
(3) Determine the adequacy of fluid therapy, vasoactive drug administration (e.g., dopamine; norepinephrine)

(4) Prevent tissue ischemia and subsequent metabolic acidosis

f. Treatment of hypotension
   (1) Rapid IV fluid administration
   (2) Decreased depth of anesthesia
   (3) Initiation of positive inotrope therapy (e.g., dopamine, dobutamine)



FIG. 14-20. Cardiac output (total blood flow) can be determined by monitoring inhaled or exhaled gases (Fick principle). The device illustrated monitors exhaled CO_2. Most other techniques for determining cardiac output (not shown) involve the intravenous administration and detection of an indicator (indicator dilution: dye, ion, cold fluid, radioactive particle)

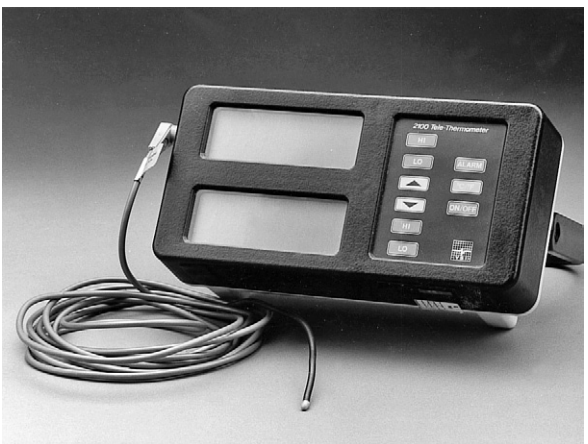


FIG. 14-21. Body temperature can be digitally displayed from a thermistor placed in the esophagus or deep into the rectum.

5. CO
   a. CO can be monitored noninvasively or minimally invasively
   b. CO = SV × HR or ABP/TPR
   c. Equipment
      (1) CO_2 rebreathing method (Fig. 14-20)
      (2) Indicator dilution method—lithium dilution thermodilution
      (3) Doppler technology

E. Musculoskeletal system (see Chapter 11)
   1. Skeletal muscle tone
   2. Quality of elicited reflexes
   3. Peripheral nerve stimulator; used to assess quality of skeletal muscle responses during onset and reversal of neuromuscular blocking drugs (see Chapter 10)

F. Body temperature (Fig. 14-21)
   1. Should be monitored during anesthesia and whenever an external heat source, (warm water blanket, warm air circulator) is used (see Chapter 17)

Incident Reporting

I. All incidents of any type should be recorded and periodically reviewed with focus on improving hospital practices and standards of care (Box 14-3, see next page).

BOX 14-3

Medical Incident Report Form

PET INFORMATION

Name:		MR #
Species/Breed:	☐ Male ☐ Neutered Male ☐ Female ☐ Spayed Female	
Color/Markings:		Date of Birth:
Diagnosis/Presenting Problem:		

CLIENT INFORMATION

Name:		
Address:		Apt. #:
City:	State:	Zip code:
Home #:	Cell:	

INCIDENT INFORMATION

Date/Time of Incident: ☐ am ☐ pm	Location of Incident:
Description of Incident (describe what happened):	
Describe injury, if applicable – include type, severity, and body part involved and action taken:	
Veterinarian's examination/findings:	
Witnesses to the Incident (list names/departments):	

REPORTER IDENTIFICATION

Name: _____	
Position/Department: _____	
Telephone/extension: _____	Email address: _____
Signature:	Date:

Acid-Base Balance and Blood Gases

15

"The management of a balance of power is a permanent undertaking, not an exertion that has a foreseeable end."
HENRY KISSINGER

OVERVIEW

Conventional approaches to the diagnosis of acid-base disorders are based upon the interpretation of changes in blood pH, carbon dioxide partial pressure (PCO_2), and bicarbonate HCO_3^- or base excess concentration. Base excess is defined as the amount of strong acid that must be added to each mL of fully oxygenated blood to return the pH to 7.40 at a temperature of 37° C and a PCO_2 of 40 mm Hg (5.3 Kilopascal [kPa]). Changes in blood pH signal either an increase (acidemia) or decrease (alkalemia) in hydrogen ion concentration and when combined with changes in PCO_2 concentration (PCO_2/pH relationship) permit the recognition of primary acid-base disturbances and the identification of respiratory and/or metabolic (nonrespiratory) disturbances (Fig. 15-1). Alternatively, the diagnosis of acid-base disorders may be determined by changes in so-called independent variables (Stewart's approach), which includes PCO_2, strong ion (e.g., Na^+, K^+, $C1^-$, Ca^{+2}, Mg^{+2}) difference, and the total concentration of nonvolatile weak acid (A_{TOT}). The aforementioned independent variables are responsible for determining the dependent variables pH and HCO_3^-. From a clinical standpoint, both approaches succeed in identifying acid-base disorders, although the latter (Stewart's approach) is more enlightening, especially when mixed acid-base and electrolyte disorders co-exist. Evaluation of an animal's acid-base status is useful for determining disease severity, diagnosing the disease, and formulating therapy.

General Considerations

I. Definitions
Acid: A substance that can donate a hydrogen ion (H+):
Carbonic acid (H_2CO_3) donates H+

$$\text{Ex.: } H_2CO_3 \rightarrow H^+ + HCO_3^-$$

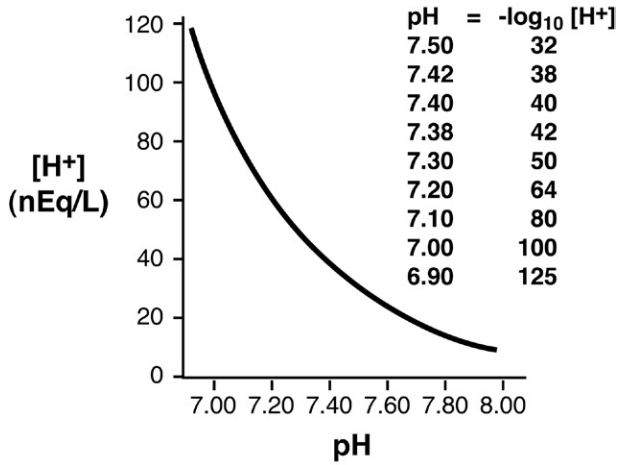


FIG. 15-1. The hydrogen ion-pH relationship. Note that a pH of 7.4 is equivalent to a hydrogen ion concentration of 40 nEq/L and that the relationship is curvilinear.

Actual bicarbonate: The amount of bicarbonate HCO_3^- expressed in milliequivalents per liter of plasma

Anion gap: The total number of cations in the extracellular fluid equals the total number of anions; however, not all anions and cations can be measured. This means that there is an apparent "gap," or difference, between the number of cations and the number of anions. This gap is the anion gap (AG). The AG represents the difference between unmeasured cations and unmeasured anions, the AG is mostly a result of the net negative charge on proteins, and is heavily influenced by protein concentration and is calculated as (Fig. 15-2)

$$AG = (Na^+ + K^+)(Cl^- + HCO_3^-)$$

Note: If a decrease in HCO_3^- is matched by an increase in chloride, the AG does not change; the acidosis is classified as hyperchloremic or normal AG acidosis. If the decrease in HCO_3 is not accompanied by an increase in chloride concentration, the acidosis is due to the addition of unmeasured anions (e.g., lactic acidosis).

A_{TOT}: Total concentration of weak acid; in plasma these consist of albumin and inorganic phosphate; increases in A_{TOT} (weak acids) can cause metabolic (nonrespiratory) acidosis; decreases in A_{TOT} cause metabolic alkalosis

Base (B): A substance that can accept a hydrogen ion (H+)

$$Ex.: OH^- + H^+ \rightarrow H_2O$$

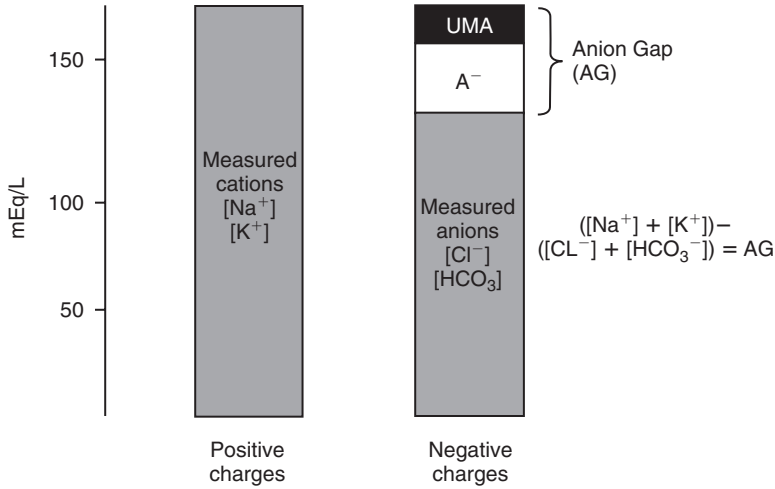


FIG. 15-2 The anion gap (AG) represents the difference between unmeasured cations (+ charge) and unmeasured anions (– charge); calculated using commonly measured chemistry values.

$$\text{AG: } \left(Na^+ + K^+\right) - \left(Cl^- + HCO_3^-\right)$$

Base excess (BE): The amount of base above or below the normal buffer base, expressed in milliequivalents per liter (mEq/L), in blood; positive values (+) reflect an excess of base (or deficit of acid), metabolic alkalosis; negative values (–) reflect a deficit of base (or excess of acid), metabolic acidosis
Note: A decrease or increase of 0.1 pH unit is equal to a decrease or increase of 7 BE units when arterial carbon dioxide partial pressure (PaCO2) is 40 mm Hg and body temperature is 37° C.
Buffer: A mixture of substances in a solution that resists or reduces changes in hydrogen ion concentration (changes in pH); important buffers in the body include hemoglobin (Hb) and bicarbonate

Components of Buffering in Blood

Buffers in Whole Blood	% Buffering
Hemoglobin and oxyhemoglobin	35
Organic phosphate	3
Inorganic phosphate	2
Plasma proteins	7
Plasma bicarbonate	35
Red blood cell (RBC) bicarbonate	18
Total	100

Free water: Water without electrolytes (pure H2O); increases in plasma free water dilute plasma constituents causing dilutional acidosis; decreases in free water concentrate plasma constituents result in alkalosis

Partial pressure: The pressure an individual gas exerts on a column of mercury; expressed in millimeters of mercury (mm Hg); 1 kPa = 7.50 mm Hg; see the following example of gaseous components of air

Composition of Air

Gas	Fractional Content (%)	Partial Pressure, mm Hg (kPa)
Nitrogen (N_2)	78.0 *	593 (79)
Oxygen (O_2)	21.0*	159 (21)
Argon (Ar)	1.0	7 (0.9)
Carbon dioxide (CO_2)	0.0	0.2
Others	0.0	0.0
Total	100	760 (atmospheric pressure)

*Partial pressure of water (PH_2O) varies according to humidity and has a proportionate effect on partial pressure of oxygen (PO_2) and partial pressure of nitrogen (PN_2). 1 kPa = 7.5 mm HG

pH: The negative log of the hydrogen ion (H+) concentration; the pH is inversely proportional to the log of the H+ concentration (see Fig. 15-1)

$$\text{Example: } (H^+) = 0.000001 = 1 \times 10^{-6} \text{ pH} = 6.0$$

$$(H^+) = 1 \times 10^{-7} \text{ pH} = 7.0$$

$$(H^+) = 1 \times 10^{-8} \text{ pH} = 8.0$$

Strong ion: A salt that is completely dissociated in water (e.g., Na^+, K^+, Cl^-, Ca^{2+}, Mg^{2+})

Strong ion difference (SID): The difference between the sums of the positive (cations) and negative (anions) strong ions; normally (Na^+, K^+, Cl^-); increases in SID usually cause metabolic (nonrespiratory) alkalosis; decreases in SID usually cause metabolic (nonrespiratory) acidosis

Strong ion gap: Because homeostasis derives from charge balance, SIDa (apparent SID) must be counterbalanced by an equal and opposing charge termed the effective strong ion

Abnormalities in Strong Ion Difference (SID) and Total Concentration of Weak Acid (A_{TOT})		
SID	Increased	Metabolic alkalosis
SID	Decreased	Metabolic acidosis
A_{TOT}	Increased	Metabolic acidosis
A_{TOT}	Decreased	Metabolic alkalosis

difference (SIDe). The SIDe negative charge principally stems from the dissociated moieties of plasma proteins (~78% albumin) and phosphate (~20%). The sum of these weak acids is known as A_{TOT} because they exist in a dissociated form (A^-) as well as an associated form (AH). When the SIDa and SIDe are equal, the plasma pH is exactly 7.4 at a PCO_2 of 40 torr. When the SIDa and SIDe are unequal, the difference between the two is termed the strong ion gap (SIG) (SIDa–SIDe, normal = 0; Fig. 15-3). This value cannot be determined by examination of other acid-base variables or schemes, and is buried within the AG along with A^- and lactate.

$$SIDa = (Na^+ + K^+) + (2 \times Ca^{2+} + 2 \times Mg^{2+}) - (Cl^- + La^-)$$

$$SIDe = HCO_3^- + A_{TOT}$$

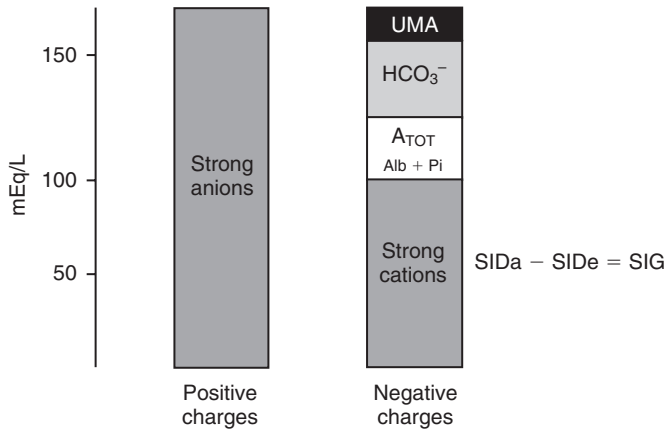


FIG. 15-3. The strong ion gap (SIG) is similar to the anion gap (AG) in that it detects the difference between unmeasured cations and unmeasured anions. The net difference between the strong cations and anions is the SIDapparent (SIDa), which is counterbalanced by A_{ToT}, also known as the SIDeffective (SIDe). SIG = SIDa – SIDe. Estimates of SIG for dogs: SIG [albumin] × 4.9 – AG; and forcats: SIG [albumin] × 7.4 – AG.

The SIG is similar to the AG and detects differences between unmeasured cations and unmeasured anions, but the SIG determines the difference between all positive and negative "strong ions": ions fully dissociated at physiologic pH and buffer ions. The strong ions include: Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^- , lactate, β-hydroxybutyrate, acetoacetate, and sulfate. Buffer ions include: HCO_3^-, albumin, globulins, and phosphate. The SIG accounts for the differences between strong cations and strong anions. The simplified SIG can be estimated using albumin concentration and AG:

$$\text{Dog SIG} = [\text{albumin}] \times 4.9 - \text{AG}$$

$$\text{Cat SIG} = [\text{albumin}] \times 7.4 - \text{AG}$$

Note: SIG increases in metabolic acidosis due to an addition of unmeasured strong ions (e.g., lactic acidosis, ketoacidosis)

Total CO_2 content: The amount of carbon dioxide gas extractable from plasma; total CO_2 consists of:

Bicarbonate (85% of the total CO_2 is HCO_3^-)
Carbonic acid (10% of the total CO_2 is H_2CO_3)
CO_2 in solution

Unmeasured anions: Strong ions (anions) that are not routinely measured (e.g., lactate; PO^{42+}, SO^{42+})

II. Many factors influence an animal's acid-base balance
- A. Species
- B. Diet (carnivorous versus herbivorous)
- C. Physical status
- D. Temperature
- E. Concentration of "strong" ions or salts that completely dissociate in water (e.g., Na^+, K^+, Cl^-, lactic acid)
- F. Total protein (albumin)
- G. Unmeasured anions (e.g., lactic acid)

III. Normal cellular metabolism continuously produces an excess of hydrogen ions, the concentration of which is regulated and eliminated by the lungs, kidneys, and gastrointestinal system to maintain an extracellular pH of approximately 7.4
- A. The kidneys eliminate hydrogen ions by excreting fixed acids and reabsorbing HCO_3^-
- B. The lungs reduce plasma hydrogen ion concentration by eliminating CO_2
- C. The kidneys and gut participate in regulating pH by modulation of acid (HCl), base (Na^+, HCO_3^-), and water excretion

IV. Substances within the body known as *buffers* (see earlier table, Components of Buffering in Blood) help minimize changes in pH (e.g., hemoglobin, HCO_3^-, HPO_4^-, $Prot^-$)

V. Determination of pH and blood gases is useful in determining the animal's acid-base status and severity of any imbalance

Formation and Elimination of Acids and Bases in Animals

I. The waste products of oral intake or metabolism (aerobic or anaerobic) are mostly acidic substances that release hydrogen ions

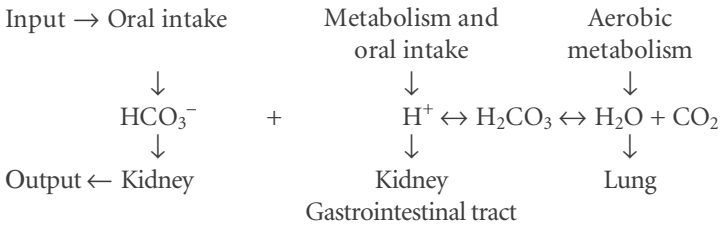
A. Volatile acid: an acid that produces a gas

$$H_2CO_3 \rightarrow H_2O + CO_2$$

B. Nonvolatile or fixed acids: acids that cannot be converted to gas

1. Lactate + H^+
2. Sulfate + H^+
3. Phosphate + H^+

II. The pathways for acid removal include the kidney, lung, and gastrointestinal tract



This is the carbonic acid equation or CO_2 hydration equation and is the basis for conventional explanations of acid-base kinetics in the body

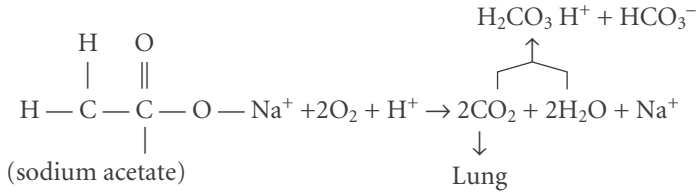
A. High-protein diets (cats, dogs, pigs, humans)

1. H^+ excess is derived from oxidation of neutral sulfur in these amino acids
   a. Methionine
   b. Cystine
   c. Cysteine

B. Diets high in plant material and grain have HCO_3^- excess from salts in:

1. Fatty acids (acetate, propionate)
2. Citrate (fruits)
3. Gluconates

Example:



Metabolizable salts of fatty acids yield HCO_3^- after metabolism

C. Based on primary dietary intake
   1. Carnivores have acid urine or excess acid to excrete (pH: 5.5 to 7.5)
   2. Herbivores have excess base to excrete (pH: 6 to 9) and produce alkaline urine and saliva

D. Dietary and metabolic intake of acid or base equals the urinary and respiratory output, thereby maintaining the pH of the body fluids near 7.4

E. Many approaches to the diagnosis and treatment of acid-base disorders are based on the following (Henderson-Hasselbalch equation):
   1. $CO_2 + H_2O \underset{\leftrightarrow}{\overset{CA}{}} H^+ + HCO_3^-$ (carbonic anhydrase [CA])
   2. $K_1 = \dfrac{[CO_2]+[H_2O]}{[H_2CO_3]}$ (K; the dissociation constant for each acid)

      $\dfrac{K_2}{K_1} = \dfrac{[H^+]+[HCO_3^-]}{[H_2CO_3]}$
   3. $\dfrac{K_2}{K_1} = \dfrac{[H^+]+[HCO_3^-]}{[CO_2]+[H_2O]} = K_3$
   4. Given: $[CO_2] = \alpha \times PCO_2$ ($\alpha = 0.0301$ – solubility coefficient)
   5. $\dfrac{K_3 \times \alpha PCO_2}{[HCO_3^-]} = (H^+)$

      $-\log (H^+) = pH$; $-\log K_3 = pK$

      pK is that pH at which 50% of an acid or a base is in the ionized state; the pK of the acid ($pK_3 = pK_a$) H_2CO_3 is 6.1
   6. $-\log K_3 - \log \alpha PCO_2 + \log[HCO_3^-] = -\log[H^+]$

      $pH = pK_3 + \log \dfrac{[HCO_3^-]}{[\alpha PCO_2]}$ (Henderson-Hasselbalch eq)

F. In the body: pH = 7.4, pK_3 = 6.1, PCO_2 = 40 mm Hg

1. $pH = pK_a + \log \dfrac{[HCO_3^-]}{[\alpha PCO_2]}$
2. $7.4 = 6.1 + \log[HCO_3^-] - \log \alpha PCO_2$
3. $1.3 = \log[HCO_3^-] - \log \alpha PCO_2$
4. $\text{Antilog } 1.3 = \dfrac{[HCO_3^-]}{0.0301 \times 40}$ $\text{antilog } 1.3 = 20$

$(HCO_3^-) = 20 \times 0.0301 \times 40 = 24$ mEq/L

Arterial Oxygenation

I. Normal gas partial pressures (expressed in millimeters of mercury) during inspiration in ambient air, conducting airways, terminal alveoli, and arterial and mixed venous blood*

Partial Pressure of Inhaled Gases, mm Hg (kPa)

	Ambient Air	Conducting Airways	Terminal Alveoli	Arterial Blood	Mixed Venous Blood
PO_2	156 (20.8)	149 (19.9)	100 (13.3)	95 (12.7)	40 (5.3)
PCO_2	0 (0)	0 (0)	40 (5.3)	40 (5.3)	46 (6.1)
PH_2O	15* (2.0)	47 (6.3)	47 (6.3)	47 (6.3)	47 (6.3)
PN_2	589 (78.5)	564 (75.2)	573 (76.4)	573 (76.4)	573 (76.4)
P total	760 (101.3)	760 (101.3)	760 (101.3)	755 (100.7)	706 (94.1)

Partial pressure of water (PH_2O) varies according to humidity and has a proportionate effect on partial pressure of oxygen (PO_2) and partial pressure of nitrogen (PN_2),
1 kPa = 7.5 mm Hg
*From Murray JF: *The Normal Lung*, ed 2, Philadelphia, WB Saunders, 1986.

II. The inspired oxygen (FIO_2)-arterial oxygen (PaO_2) relationship

A. Relationship between FIO_2 and PaO_2

The Effect of Inspired Oxygen Fraction on Partial Pressure of Oxygen

	Predicted Ideal PaO_2	
FIO_2 (%)	**(mm Hg)**	**(kPa)**
20	95-100	12.6-13.3
30	150	20.0
40	200	26.6
50	250	33.3
80	400	53.2
100	500	66.5

B. The alveolar gas equation

$$PAO_2 = PIO_2 - \frac{PaCO_2}{0.8}$$

III. Causes of arterial hypoxia (a reduction in PaO_2) and their effect on alveolar-arterial $P(A\text{-}a)O_2$ differences ($[A\text{-}a]O_2D$)

Arterial Hypoxemia Causes

Cause	Effect on Arterial PO_2	Effect on $(A\text{-}a)O_2D$
Hypoventilation	Decreased	No change
Diffusion abnormality	No change or decreased*	No change or decreased*
Ventilation perfusion imbalance	Decreased	Increased
Right-to-left shunt	Decreased	Increased
Reduction in inspired PO_2	Decreased	No change

*Effects of diffusion abnormalities are infrequently encountered at rest and are most likely to be evident during exercise.

IV. Oxygenation

A. Efficiency of oxygenation

1. $P(A\text{-}a)O_2$ Difference
2. PaO_2/PAO_2
3. Right-to-left shunt (when breathing 100% O_2)

$$Qs\ (\text{shunt blood flow}) = \frac{(PAO_2 - PaO_2)(0.003)}{4 + (PAO_2 - PaO_2)(0.003)}$$

B. Adequacy of tissue oxygenation (partial pressure of venous oxygen; PvO_2)

Oxygen Delivery to Tissues

I. Dissolved

A. Henry's law: amount of O_2 dissolved is proportional to PO_2; for each 1 mm Hg of PO_2, there is 0.003 mL O_2/100 mL of plasma; content = solubility partial pressure

B. Dissolved O_2 is not adequate to meet the animal's oxygen needs

II. Hemoglobin

A. Conjugated protein of iron and porphyrin joined to the protein globin; globin has two alpha and two beta chains made of differing amino acid sequences

1. Hb A: adult
2. Hb F: fetal

3. Hb S: sickle (valine-glutamic acid); poor oxygen-carrying capability

B. Hb A is transferred from a ferrous to a ferric ion by oxidation (methemoglobin), which is not useful in O_2 carriage
   1. Nitrites
   2. Sulfonamides
   3. Benzocaine

C. Carboxyhemoglobin (COHb) is a stable complex of carbon monoxide (CO) and Hb that forms in RBCs when CO is inhaled (smoke inhalation)
   1. Hb binds preferentially to CO compared with O_2 (approx 240:1) such that Hb will not transport O_2

Oxygen Dissociation Curve (Fig. 15-4)

I. $O_2 + Hb = HbO_2$ (oxyhemoglobin); O_2 capacity is the amount of O_2 that can be combined with Hb; 1 g Hb can combine with 1.34 to 1.39 mL of O_2; For example, if there is 15 g Hb, then $1.39 \times 15 = 20.8$ mL O_2/100 mL at 100% saturation

II. O_2 saturation

$$\frac{O_2 \text{ combined with Hb} \times 100}{O_2 \text{ capacity}}\%$$

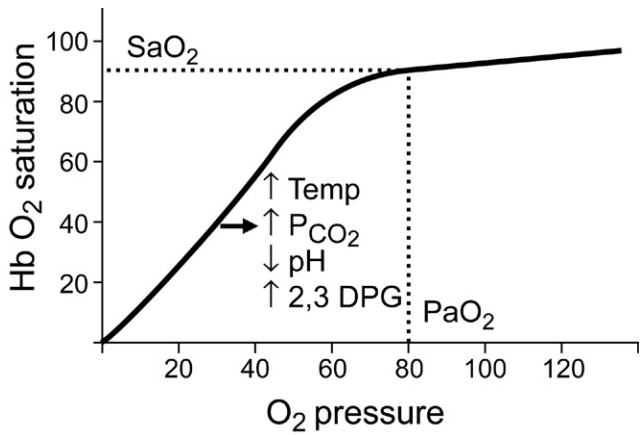


FIG. 15-4. The oxyhemoglobin dissociation curve. The effects of pH, carbon dioxide partial pressure (PCO_2), temperature, and 2, 3-diphosphoglycerate on hemoglobin (Hb) saturation with oxygen (O_2) are noteworthy, as is the effect of anemia (low Hb) on O_2 content. Note that Hb begins to desaturate at about 60 mm Hg.

III. O_2 content is the amount of O_2 present as dissolved O_2 and the amount combined with Hb. Example: What is the O_2 content of blood if the Hb concentration is 12 g/dL and the Hb saturation is 96% when the PaO_2 is 100 mm Hg?

$$1.39\ \text{mL}\ O_2 \times 12\ \text{g (Hb)} \times 96\% = 16\ \text{mL}\ O_2\ \text{(with Hb)}$$

$$+)\ 100\ \text{mm Hg}\ (PaO_2) \times 0.003\ \text{mL}\ O_2/\text{mm Hg} = 0.3\ \text{mL}\ O_2\ \text{(in plasma)}$$

$$16.3\ \text{mL}\ O_2/100\ \text{mL}\ (O_2\ \text{in blood})$$

IV. O_2 dissociation curve shape (see Fig. 15-4)

A. Upper portion: PO_2 (partial pressure of O_2) can fall slightly without affecting O_2 loading of hemoglobin

B. Lower portion: peripheral tissues can withdraw large amounts of O_2 with only small changes in PO_2

1. Note: more than 5 g/dL of deoxygenated (unsaturated) Hb can cause cyanosis (blue or purple discoloration of the mucous membranes)

V. Shifts in the O_2-dissociation curve are most commonly caused by changes in pH, PCO_2, and temperature

A. Increasing temperature and PCO_2 and decreasing pH shifts the O_2 dissociation curve to the right; reverse changes have the opposite effect

B. 2,3-Diphosphoglycerate increases within RBCs in chronic hypoxia and shifts the O_2-dissociation curve to the right

C. Rightward shifts mean more unloading of O_2 at a given PO_2; normal PO_2 at 50% O_2 saturation (P50) is approximately 26 mm Hg in a capillary

D. Deoxygenated Hb can carry more CO_2

Carbon Dioxide

I. Transport

A. Dissolved in blood

1. In plasma (as HCO_3^-): 85%
2. In RBCs as carbamino compounds
3. Carried in physical solution

B. The measurement of end-expired CO_2 ($ETCO_2$) and $PaCO_2$ permits the calculation of dead space ventilation (VD). Referred to as the alveolar dead space or Bohr equation

$$VD = \frac{PaCO_2 - ETCO_2}{PaCO_2}$$

Carbon Monoxide

I. Hb + CO→COHb (carboxyhemoglobin)

II. CO has approximately 210 times the affinity for Hb as O_2 (see above)

A. Small amounts of CO can tie up large amounts of Hb, making it unable to carry O_2

B. PaO_2 is normal, but O_2 content is dramatically reduced

C. The oxyhemoglobin curve is shifted to the left, impairing O_2 unloading in tissues

Normal pH and Blood Gas Values

I. pH = 7.40; range 7.35 to 7.45

II. PaO_2 = 95 mm Hg; range 80 to 110 mm Hg

III. PvO_2 = 40 mm Hg; range 35 to 45 mm Hg

IV. $PaCO_2$ = 40 mm Hg; range 35 to 45 mm Hg

V. $PvCO_2$ = 45 mm Hg; range 40 to 48 mm Hg

VI. HCO_3^- = 24 mEq/L; range 22 to 27 mEq/L (a little higher in horses and ruminants)

The $PaCO_2$/pH/HCO_3^- Relationship

$PaCO_2$ (mm Hg) (acute change)	pH	HCO_3^- (mEq/L) (Effect)
80	7.2	28
60	7.3	26
40	7.4	24
30	7.5	22
20	7.6	20

VII. Nomenclature

A. **Acidemia:** pH less than 7.35 (acid blood)

1. Metabolic or nonrespiratory acidosis: an abnormal physiologic process characterized by a primary gain of acid (H^+) or primary loss of base (HCO_3^-) from the extracellular fluid
2. Respiratory acidosis: an abnormal process in which there is a primary reduction in alveolar ventilation relative to CO_2 production ($PaCO_2$ increase)

B. **Alkalemia:** pH greater than 7.45 (alkaline blood)

1. Metabolic alkalosis or nonrespiratory alkalosis: an abnormal physiologic process characterized by a primary

gain in base (HCO_3^-) or loss of acid (H^+) from the extracellular fluid

2. Respiratory alkalosis: an abnormal physiologic process in which there is a primary increase in alveolar ventilation relative to the rate of CO_2 production ($PaCO_2$ decrease)

C. **Compensation:** return of an abnormal pH toward normal by altering the component not primarily affected; for example, if the $PaCO_2$ is elevated, the HCO_3^- should be elevated (retained) to compensate

1. If the $PaCO_2$ or HCO_3^- values are outside normal limits, but the pH is within the normal range, the animal is fully compensated
2. It takes time for the process of compensation to return pH to within normal limits; a compensatory process implies a degree of chronicity
   a. Respiratory compensation occurs within a few minutes after primary insult, but a few hours are required to reach highest efficacy
   b. Renal compensation for primary respiratory effects takes at least a few hours, but days are required to reach highest efficacy
3. It is important to determine primary or secondary (compensatory) changes

Primary pH and Blood Gas Classification

Classification	$PaCO_2$	pH	HCO_3^-	BE
Acute ventilatory failure	↑	↓	N	N
Chronic ventilatory failure	↑	N	↑	↑
Acute alveolar hyperventilation	↓	↑	N	N
Chronic alveolar hyperventilation	↓	N	↓	↓
Uncompensated metabolic acidosis	N	↓	↓	↓
Compensated metabolic acidosis	— ↓	N	↓	↓
Uncompensated metabolic alkalosis	N	↑	↑	↑
Compensated metabolic alkalosis	↑	N	↑	↑

BE, Base excess, ↓, decreased; ↑, increased; N, normal.

VIII. Mixed respiratory and metabolic conditions can coexist; when this occurs, look at the individual values (pH, PCO_2, HCO_3^-, or base excess) to determine the severity

Rapid Qualitative Interpretation of pH and Blood Gases

I. Determine pH: acidemia or alkalemia; the pH is the most important value in determining the animal's acid-base status; match subsequent values to it

II. Determine PCO_2
- A. Respiratory alkalosis: less than 35 mm Hg
- B. Respiratory acidosis: greater than 50 mm Hg

III. Determine BE or HCO_3^-
- A. Metabolic alkalosis: BE of greater than +5 mEq/L ($HCO_3^- > 28$ mEq/L)
- B. Metabolic acidosis: BE of less than −5 mEq/L ($HCO_3^- < 20$ mEq/L)

IV. Determine the primary problem by matching either the PCO_2 or BE or both with the pH; determine whether compensation exists (pH near normal)

V. Look more closely at BE
- A. BE can be influenced by four factors:
  1. Free water (use $[Na^+]$ as the measure): Na^-, K^+, and Cl^+ are examples of strong ions
  2. $[Cl^-]$
  3. Protein concentration (A_{TOT})
  4. Unidentified anion concentrations (e.g., lactic acid)
- B. Abnormalities in all four can exist simultaneously (Fig. 15-5); they can have opposite effects and therefore can offset and mask each other; for example, severe lactic acidosis from shock can be offset by a severe hyperchloremic alkalosis from sustained vomiting; the net (observed) BE could be zero

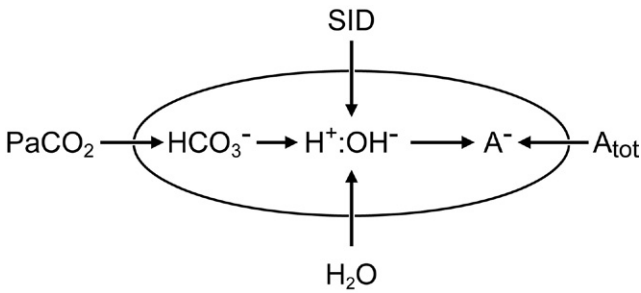


FIG. 15-5. Factors that affect acid-base balance. Note that H^+ concentration is dependent upon arterial carbon dioxide partial pressure ($PaCO_2$), strong ion difference (SID), and total concentration of weak acid (A_{TOT})

VI. Determine PaO_2
- A. If PaO_2 is less than 80 mm Hg, suspect hypoxemia
- B. Remember, 5 g/dL of unoxygenated Hb results in cyanosis in animals with more than 5 g/dL of Hb

Principles of Practice

I. The HCO_3^- concentration increases about 1 to 2 mEq/L for each acute 10 mm Hg increase in $PaCO_2$ above 40; maximum chronic compensatory change in HCO_3^- is approximately 4 mEq/L

II. The HCO_3^- concentration falls 1 to 2 mEq/L for each acute 10 mm Hg decrease in $PaCO_2$ below 40; maximum chronic compensatory change in HCO_3^- is approximately −6 mEq/L

III. Acute respiratory and nonrespiratory disorders can be distinguished by their BE, $PaCO_2$, and HCO_3^- or BE values; BE of more than 5 or less than −5 and HCO_3^- of more than 30 or less than 15 mEq/L imply a nonrespiratory (metabolic) component

IV. During chronic elevation of the $PaCO_2$ (hypercapnia), each 10 mm Hg increase in $PaCO_2$ causes a 4 mEq/L increase in HCO_3^- concentration

V. An acute 10 mm Hg increase in $PaCO_2$ results in a 0.05 unit decrease in pH; an acute 10 mm Hg decrease in $PaCO_2$ results in a 0.10 unit increase in pH

VI. Rapid determination of the predicted respiratory pH
- A. Determine the difference between the measured $PaCO_2$ and 40 mm Hg (the respiratory component)
- B. If the $PaCO_2$ is greater than 40, move the decimal two places to the left and subtract half the value from 7.40
- C. If the $PaCO_2$ is less than 40, move the decimal two places to the left and add the value to 7.40
- D. Examples:
  1. pH = 7.01; $PaCO_2$ = 75 ($PaCO_2 > 40$ mm Hg)
     $75 - 40 = 35; 0.35 \times 0.5 = 0.175$
     $7.40 - 0.175 = 7.23$
  2. pH = 7.43; $PaCO_2$ = 23 ($PaCO_2 < 40$ mm Hg)
     $40 - 23 = 17$
     $7.40 + 0.17 = 7.57$

VII. Rapid determination of the metabolic (nonrespiratory) component
- A. A 10 mEq/L change in HCO_3^- concentration changes pH by 0.15 units; if the pH decimal is moved two places to the right, then a 10:15 or two-thirds relationship exists

B. The absolute difference between the measured pH and the predicted respiratory pH is the metabolic component of the pH change; moving the decimal point two places to the right and multiplying by two thirds yields an estimate of the mEq/L variation of the buffer baseline (usually assumed as the HCO_3^- concentration change)

VIII. Rapid quantitative clinical determination of acid-base changes

A. Determine the predicted respiratory component of the pH change

B. Estimate BE or deficit

C. Examples (see VII above):

1. pH = 7.02; $PaCO_2 = 75$
   Predicted respiratory pH:
   $75 - 40 = 35; 0.35 \times 0.5 = 0.175$
   $7.40 - 0.18 = 7.22$
   Metabolic (nonrespiratory) component:
   $7.22 - 7.02 = 0.2; 20 \times 2/3 = 13.3$ mEq/L,
   or 13.3 mEq/L base deficit
2. pH = 7.64; $PaCO_2 = 25$
   Predicted respiratory pH:
   $40 - 25 = 15; 0.15$
   $7.40 + 0.15 = 7.55$
   Metabolic component:
   $7.64 - 7.55 = 0.09; 9 \times 2/3 = 6$ mEq/L, or 6.0 mEq/L BE

IX. Quantitative analysis of metabolic or nonrespiratory acid-base ratio state*

A. Enter the observed BE at the bottom of Table 15-1

TABLE 15-1 Quantitative Analysis of Nonrespiratory Acid-base Problems

Free water abnormalities:	0.3 ($[Na^+] - 140$)	—
Chloride abnormalities:	$102 - [Cl^-]corr$	—
Hypoproteinemia:	$3(6.5 - [P_{TOT}])$	—
Unmeasured anions make up the balance:		—
Total, or the observed (reported) BE:		—

([ ] = measured value)
$[Cl^-]corr = [Cl^-]obs \times 140/[Na^+]$.
For [Alb] instead of $[P_{TOT}]$, use 3.7 (4.5 − [Alb]).

*Modified from Leith DE: Proceedings of the Ninth ACVIM Forum, New Orleans, May 1991.

B. Calculate and enter the expected contributions to BE caused by the following:
   1. Any free water abnormality
   2. Abnormalities in the corrected $[Cl^-]$
   3. Abnormalities in protein concentrations; be careful about signs (+ or −)

C. Algebraically sum the values in "B" in this outline to determine whether there are unmeasured anions; be careful about sign (+ or −)

D. Compare "A" and "C"; the observed BE should never be greater than the summed values in "C"; if the observed BE is less, the presence of unmeasured anions (UA^-) equal in magnitude to the difference of the summed values in B and BE can be inferred

X. Example (see Table 15-1)

If:

$pH = 7.250, Na^+ = 135$
$PCO_2 = 75, Cl- = 79$
$BE = 2; P_{TOT} + 8.4$

Then:

Free water abnormality = −1.5
Chloride abnormality = +20.1
Hyperproteinemia = −5.7
Observed BE = 2

Therefore:

$UA^- = 14.9$
$[(12.9) + (2) = 14.9]$

This animal has considerable unmeasured ions (14.9 mEq/L), which suggests a severe nonrespiratory acidosis

XI. Summary of acid-base disorders

A. All acid-base disturbances are caused by changes in $PaCO_2$, SID, and P_{TOT}

B. Because protein concentration is not manipulated clinically, all acid-base disturbances are corrected by changes in $PaCO_2$ and SID

XII. Therapy

A. Base deficits of less than 10 mEq/L can be but are not routinely treated; they are usually treated by improving blood pressure and blood flow

B. A pH of higher than 7.20 is not routinely treated unless there is evidence of poor blood pressure or blood flow

C. Because extracellular water is approximately 20% body weight (intravascular fluid 5% and the interstitial fluid 15%), base deficits × body weight (kg) 20% = amount of HCO_3^- needed as replacement, or

$$\frac{\text{Base deficit} \times \text{wt (kg)}}{4} = \text{mEq } HCO_3^- \text{ required}$$

Common Causes of Acid-Base Imbalance

I. Respiratory acidosis
- A. Anesthesia or respiratory depressant drugs
- B. Obesity
- C. Pulmonary disease
- D. Rib or thoracic disease; trauma
- E. Airway obstruction
- F. Brain damage
- G. Hypoventilation during artificial ventilation
- H. Potential cause: a stuck open expiratory one-way breathing valve in a circle anesthetic system

II. Respiratory alkalosis
- A. Anxiety, fear
- B. Pain
- C. Hyperthermia
- D. Fever
- E. Endotoxemia
- F. Pneumonia, pulmonary embolus
- G. Hypoxemia, anemia
- H. Left-to-right shunts
- I. Heart failure
- J. Central nervous system disease

III. Metabolic acidosis
- A. Poor tissue perfusion (lactic acidosis)
  1. Low blood pressure; blood flow
  2. Ischemic tissues
- B. Renal disease (uremia)
- C. Chronic vomiting
- D. Diarrhea
- E. Exercise fatigue, hypoxia, shock, trauma
- F. Diabetes mellitus
- G. Hypoaldosteronism

IV. Metabolic alkalosis
- A. Acute vomiting
- B. Hypochloremia
- C. Excessive use of diuretics
- D. Cushing's syndrome
- E. Excessive administration of HCO_3^-

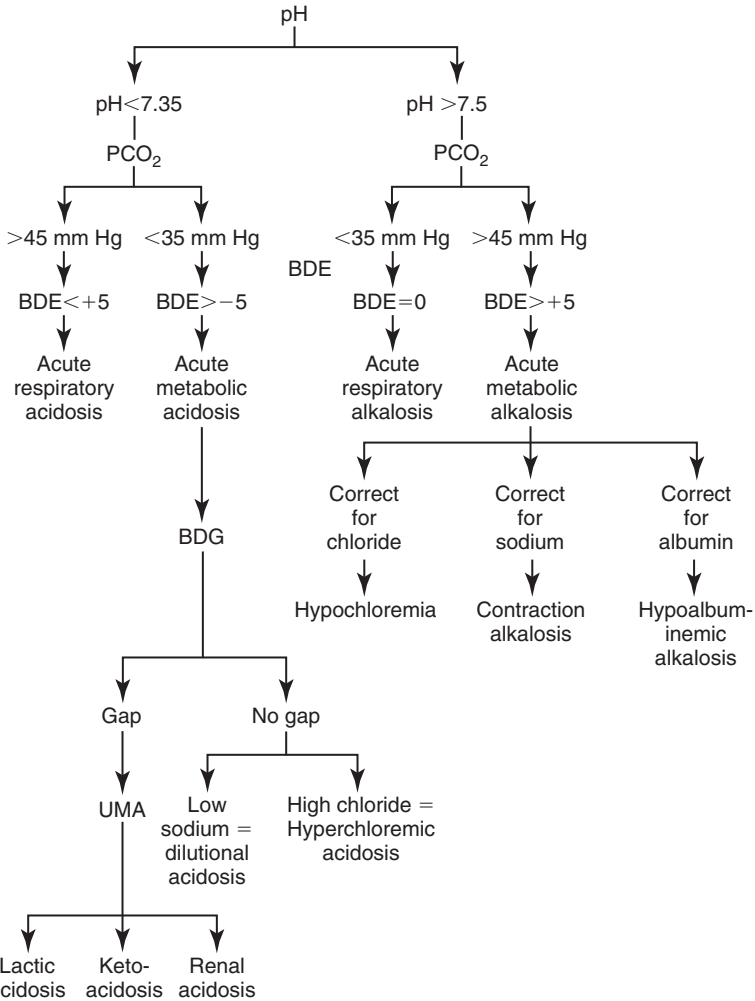


FIG. 15-6. Algorithm for acid-base interpretation. BDE, Base deficit/excess (–/+); BDG, base deficit gap (difference between measured and calculated base excess [BE]); UMA, unmeasured anions.

Acid-Base and Electrolyte Interrelationships (Fig. 15-6)

I. Most CO_2 entering the blood passes into RBCs, where it enters into a reversible formation with HCO_3

$$CO_2 + H_2O \overset{CA}{\leftrightarrow} H_2CO_3^- \overset{CA}{\leftrightarrow} H^+ + HCO_3^-$$

The HCO_3^- formed by this reaction diffuses out of RBCs; this movement sets up an electrostatic difference across the cell membrane, which is neutralized by the movement of Cl^- from plasma into the RBC (chloride shift)

II. The location and absolute numbers of positively and negatively charged ions (strong ions) and their difference in combination with CO_2 production, the resultant PCO_2, and the total protein determine pH (H^+) and (HCO_3^-) changes in the body

III. Changes in strong ions in various body fluids result in changes in SID, which provide the major mechanism for acid-base interactions

IV. AG and SIG can be used to identify and differentiate acid-base disorders

A. Normal: If the AG or SIG are normal in the face of metabolic acidosis, the acidosis is caused by increased chloride (measured anion)

B. Increased: If there is AG or SIG metabolic acidosis, it indicates that there are unmeasured anions in the extracellular fluid, as with ethylene glycol toxicity. Clinical signs are attributable to the underlying disease leading to the metabolic acidosis and increase the SIG and AG. Examples include uremia (sulfates and phosphates), tissue hypoxia (lactate), and diabetic ketoacidosis (ketones).

C. Decreased: A low AG is infrequently identified but can be seen with hypoalbuminemia. The SIG is not affected by albumin concentration.

V. To maintain electrical neutrality, electrolyte shifts generally occur simultaneously with acid (H^+) or base HCO_3^- shifts; the most important electrolyte shift occurring with acid-base changes is K^+; for example, when HCO_3^- is added to the extracellular fluid, hydrogen ions (H^+) leave cells, causing K^+ to move intracellularly to maintain electrical equilibrium; therefore:

A. In metabolic alkalosis, suspect hypokalemia

B. In metabolic acidosis, suspect hyperkalemia

16 Perioperative Fluid Administration

"One can drink too much, but one never drinks enough."
GOTTHOLD EPHRAIM LESSING

OVERVIEW

Perioperative fluid therapy is a vital adjunct to any anesthetic plan. The term *perioperative* is defined as the period of time extending from when the animal goes into the hospital, clinic, or veterinarian's office for surgery until the time the animal is discharged home. Almost all drugs used to produce anesthesia decrease the force of cardiac contraction and cause vasodilatation thereby increasing intravascular volume and resulting in relative hypovolemia. These effects generally lead to decreased cardiac output (blood flow) and arterial blood pressure (BP). It is important to remember that intravenous (IV) fluids are drugs and that their administration during anesthesia helps maintain an adequate and effective circulating blood volume, improve cardiac output, and enhance tissue perfusion. Additionally, perioperative fluid therapy is frequently administered to treat electrolyte and acid-base disorders. The choices for acute fluid therapy frequently include balanced electrolyte solutions (crystalloids), colloids, plasma, cell-free blood substitutes, and blood.

General Considerations (Table 16-1)

I. Anesthesia, surgery, and many of the diseases for which surgical intervention is required disturb cardiac function, smooth muscle vascular tone, blood flow distribution, plasma electrolyte concentrations and acid-base balance potentially altering the effective circulating blood volume (the volume circulating).

A. Many diseases produce changes in the relative or absolute blood volume, electrolyte concentrations, and acid-base balance (Table 16-2)

B. Common side effects of anesthesia

1. Inhalant and/or IV anesthesia

a. Decrease myocardial contractility, cardiac output and tissue perfusion

TABLE 16-1 Normal Electrolyte Composition of Serum (mEq/L)

Animal	Na^+	K^+	Ca^{++}	Mg^{++}	HPO_4	Cl^-	HCO_3
Dog	143-153	4.2-5.4	5.0-6.1	0.43-0.60	3.2-8.1	109-120	18-25
Cat	146-156	3.2-5.5	4.9-5.5	0.43-0.70	3.2-6.5	114-126	18-22
Horse	132-142	2.4-4.6	6.0-7.2	0.46-0.66	1.2-4.8	97-105	23-31
Cow	133-143	3.9-5.2	8.9-5.4	0.47-0.65	3.8-7.7	98-108	23-31

TABLE 16-2 Common Diseases And Expected Electrolyte Abnormalities

Disease Syndrome	Water	Na^+	K^+	Ca^{++}	Mg^{++}	HPO_4	Cl^-	HCO_3
Gastric loss, vomiting	Loss	↓	↓		↓		↓	—↑
Pancreatic or intestinal fluid loss	Loss	↓	↓		↓		↓	↓
Diarrhea	Loss	↓	↓		↓		↓	↓
Starvation	Loss		↓↑	↓	↓			
Acute hemorrhagic pancreatitis	Loss	—↓	—↓	↓			↓	
Malabsorption syndrome	Loss			↓	↓	↓		
Acute renal failure (oliguric)	Excess	—↑↓	↑	↓	↓	↑	↑	↓
Renal tubular dysfunction	Loss	↓	—↓					↓
Chronic renal disease	Loss	—↓	—↓↑	—↓	↑	—↑	—↓	↓
Diabetes insipidus	Loss	↑				↑		
Burns	Loss	↓	↑	↓				
Primary aldosteronism	Excess	↑—	↓		↓		↓	↑
Stress, surgery, including antidiuretic hormone	Excess	↓						↓
Hypoadrenocorticism (Addison's disease)	Loss	↓	↑	—↑	↑	—↑	—↓	↓
Hypopituitarism	Excess	↓						
Hyperadrenocorticalism (Cushing's disease)	Excess	—↑	↓	↓				↑
Excess citrated blood				↓				
Hyperparathyroidism			↑	↑	↓	↓		
Excess lactation (milk fever)				↓	↓	↓		
Acidosis (metabolic)				↑			—↑	↓
Alkalosis (metabolic)				↓			↓	↑

↑, Increased serum concentration; ↓, decreased serum concentration; —, normal serum concentration.

b. Produce vasodilation; relative hypovolemia; hypotension is one of the most common, if not the most common side effects of general anesthesia in most species
c. Depress minute ventilation; respiratory acidosis may occur
d. Decrease urine production and renal concentrating ability
e. Predispose to hypothermia
f. Depress autoregulatory compensatory mechanisms

2. General anesthesia usually depresses sympathoadrenal and compensatory reflex responses to hypotension, hypercapnia, and hypoxemia

C. Imbalances associated with or caused by surgery
1. Vasodilatation (relative hypovolemia)
2. Blood loss (absolute hypovolemia)
3. Evaporative fluid loss from exposed tissues
4. Pain-induced redistribution of fluids

II. Fluid loss leads to a decrease in the "effective" circulating blood volume eventually resulting in a decrease in cardiac output, a redistribution of blood to vital organs (heart, brain, lung), and the development of metabolic acidosis

III. Fluid administration in young or small animals (<3 kg) should be supplemented with a source of calories (dextrose) and monitored closely to prevent hypothermia and/or overhydration

IV. The administration of large quantities of room-temperature fluids to any animal can produce hypothermia and hemodilution, resulting in coagulation abnormalities

Normal Body Water Distribution (Fig. 16-1)

I. Total body water represents 55% to 75% of body weight (use 60%), primarily depending on the animal's age and percentage of body fat

II. Extracellular water (ECW): the water outside cells and constituting the blood (plasma; red blood cells [RBCs]) volume and interstitial fluid volume. ECW ranges from 23% to 33% of body weight (use 30%); the percentage is greater in very young animals

III. Interstitial water constitutes 15% to 25% of body weight

IV. Plasma water constitutes approximately 5% of body weight

V. Extracellular water equals plasma water plus interstitial water

VI. Intracellular water constitutes 35% to 45% of body weight

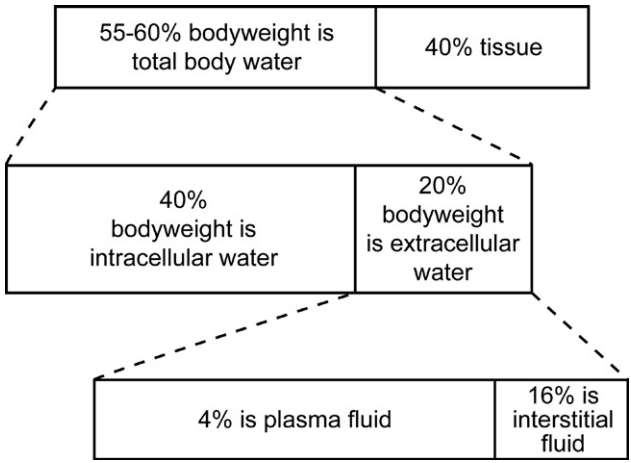


FIG. 16-1. Approximate distribution of body fluids among the intravascular, interstitial (extracellular), and intracellular fluid compartments. Approximately 60% of the body is water. This value may be larger (70%) in neonates.

VII. Blood volume constitutes 8% to 10% of body weight (approximately 90 mL/kg of body weight), depending on the hematocrit; hematocrit measures how much space in the blood is occupied by RBCs and is also referred to as the *packed red cell volume* or *packed cell volume* (PCV) and abbreviated as Hct or Crit

A. Blood volume equals plasma volume plus RBC volume

Electrolyte Distribution

I. Extracellular water contains large quantities of salt: sodium and chloride ions. The extracellular fluids (plasma and interstitial fluid) also contain smaller quantities of other solutes

A. Blood contains RBCs and plasma. Plasma is a complex fluid that contains water and other solutes including electrolytes (see Table 16-1), proteins (albumin), large glycoproteins (antibodies: immunoglobulins), glucose and many other substances

1. Plasma osmolarity is a measure of the concentration of substances such as sodium, chloride, potassium, urea, glucose, and other ions in blood. It is calculated as the osmoles of solute per kilogram of solvent.

a. plasma osmolarity = 2[Na+] + [Glucose]/18 + [Blood urea nitrogen]/2.8

2. The plasma osmolarity is sensitive to changes in hydration status during dehydration and rehydration. The normal plasma osmolarity ranges from 280 to 300 mOs/kg

II. Intracellular water contains large quantities of potassium ions

Principles of Fluid Administration

I. Correct dehydration and electrolyte and acid-base imbalances 12 to 24 hours before anesthesia when possible

II. Do not attempt to replace dehydration or chronic fluid losses acutely; severe dilution of plasma proteins, RBCs, and electrolytes may be produced (see Table 16-2)

A. Normal daily fluid maintenance rates vary as follows:
   1. Mature animal: 30 to 60 mL/kg/day
   2. Young animal: 40 to 80 mL/kg/day

B. Calculation of replacement fluid volume in dehydrated animals
   1. Body weight (kg) × % dehydration (figured as a decimal) = fluid deficit (L) (e.g., 20 kg × 10% dehydration = 2 L fluid deficit); reassess periodically to determine the response to volume administered

Dehydration in Animals

Organ	Minimal (4%)	Moderate (6% to 8%)	Severe (10% to 12%)
Skin resiliency	Pliable	Leathery	Absolutely no pliability
Skin tenting	Tented skin immediately disappears and tent persists up to 2 sec	Tented skin slowly disappears and tent persists up to 3 sec or more	Twisted and tented skin persists indefinitely
Eye	Bright Slightly sunken	Duller than normal Obviously sunken	Cornea dry Deeply sunken, 2- to 4-mm space between eyeball and bony orbit
Mouth	Moist, warm	Sticky to dry, warm	Dry, cyanotic

2. Fluid administration to correct dehydration should be administered over a 6- to 12-hour period or added to the maintenance fluid volume and administered over a 24-hour period

III. Monitor hemodynamics, pulmonary, and renal function when administering fluids rapidly

A. Cardiac function
   1. Monitor arterial BP; systolic BP >90 mm Hg; mean BP >60 mm Hg
   2. Auscultate the chest; if the total protein (TP) drops below 3.5 g/dL from fluid administration, pulmonary edema may occur
   3. Central venous pressure (0.5 to 5.0 cm H_2O) or pulmonary capillary wedge pressure (5 to 10 mm Hg) can be monitored, although their predictive value for determining rates and volumes of fluid administration is low unless fluids are administered in excess or the animal develops right heart failure
   4. Measures of systolic arterial pressure variation (SPV) or pulse–oximeter-derived plethysmographic variability index (PVI) provides valuable information regarding fluid requirements and the effectiveness of fluid administration (see: Chapter 14)
      a. PVI: pleth variability index, is a noninvasive method for optimizing fluid administration and predicting fluid responsiveness in mechanically or manually ventilated animals during general anesthesia
      b. PVI improves fluid management and helps to detect hypovolemia

B. Renal function
   1. Improve or reestablish renal perfusion and urine production (0.5 to 2.0 mL/kg/hr) before anesthesia
   2. Administer mannitol at 1 to 2 g/kg IV over a 30-minute period to induce urine production in animals with normal hydration

C. Pulmonary function—overhydration can lead to pulmonary edema initially exemplified by increases in respiratory rate, increased breathing effort (abdominal contraction) and increased lung (bronchovesicular) sounds (Box 16-1).

BOX 16-1

End Points for Monitoring Fluid Resuscitation

Variable	Resuscitation End Point
Mentation	Alert
Heart rate (beats/min)	Dog: 70-130 Cat: 120-180
Mucous membrane color	Pink
Capillary refill time (seconds)	1-2
Rectal temperature (°F)	99-101
Mean arterial blood pressure (mm Hg)	60-80
Systolic arterial blood pressure (mm Hg)	80-100
Central venous pressure (cm H_2O)	5-10
Urine output (mL/kg/h)	>0.5
SpO_2 (%)	>95
$SCVO_2$ (%)	<60
PCV (%)	>21
Hemoglobin (g/dL)	>7
Lactate (mmol/L)	<2
pH	>7.32
Base deficit (mEq/L)	–2 to +2
COP (mm Hg)	14-20

COP, Colloid oncotic pressure; *PCV*, packed cell volume; *SpO_2*, arterial oxygen saturation; *$SCVO_2$*, central venous oxygen saturation.

Fluid Administration During Anesthesia (Table 16-3; Boxes 16-2 and 16-3)

I. Fluids administered during anesthesia are usually polyionic isotonic crystalloid solutions (Tables 16-4 and 16-5)

A. Crystalloids are solutions of small molecules (e.g., Na^+, Cl^-) that pass freely through vascular walls and cell membranes (e.g., Ringer's solution, 5% dextrose in water)

B. Colloid solutions are a homogeneous mixture of one or more substances (solutes) dispersed molecularly in a sufficient quantity of dissolving medium (solvent)

1. Colloids are particles that are larger than 30,000 Daltons (30 kDa)
2. Colloids can be natural (albumin: 69 kDa) or synthetic (gelatins; dextrans; starches)
   a. Hydroxyethyl starches are the most popular colloids used in veterinary practice

C. Fluid administration (see Tables 16-3 and Box 16-2)

TABLE 16-3 Categories, Distribution, and Clinical Indications for Commonly Available Fluids for Intravenous Fluid Therapy

Fluid Type	Example	Volume Needed to Increase Plasma Volume by 1 Liter	Distribution	Examples of Clinical Indications
Colloid	Starch	1 L	Plasma volume	Hypovolemia, hypotension, normovolemic hemodilution, hypoalbuminemia
Hypertonic crystalloid	7.5% Saline (NaCl)	300 mL	Immediate plasma volume expansion causing ICFV reduction	Hypovolemic shock, cerebral edema
Isotonic crystalloid	0.9% NaCl, lactated Ringer's solution	4 L or more	ECFV (plasma volume and ISFV expansion)	Dehydration, hypovolemia, hypotension, normovolemia, hemoconcentration

ECFV, Extracellular fluid volume; *ICFV*, intracellular fluid volume; *ISFV*, interstitial fluid volume.

1. Most fluid administration sets deliver 10 drops/mL (regular drip) or 60 drops/mL (mini-drip)
2. Larger diameter needles or IV catheters offer less resistance to fluid flow and increase the rate of fluid administration
3. Occasionally, fluids are administered at extremely rapid rates (>90 mL/kg/hr) with fluid pumps
4. Infusion pumps and syringe infusion pumps facilitate delivery of accurate volumes of fluid (Figs. 16-2 and 16-3)

II. Rate of initial crystalloid fluid administration depends on fluid loss during surgery

A. Initial minimal rates of fluid administration:

Replacement Rates for Crystalloids	
Small animals	3-10 mL/kg/hr
Large animals	3-5 mL/kg/hr
Blood loss	3 mL crystalloid or 1-1.5 mL colloid/1 mL blood

BOX 16-2

Guidelines for a "Recipe-Based" Approach for Crystalloid Fluids Administration

Step 1
Start IV fluids, replace insensible (feces, saliva, skin, respiratory tract ≅ 20 mL/kg/day) loss with maintenance-type solutions, 2 to 3 mL/kg/hr, during interval since last oral intake. Example:
10 kg dog; 3 hr since oral H_2O intake
10 kg × 3 (hr) × 3 mL = 90 mL added to first hour of basal fluids

Step 2
Basal fluid administration solution for intraoperative losses. Administer lactated Ringer's solution or Normosol-R

Step 3
Estimate surgical trauma and add appropriate volume of replacement-type solution to that given in Step 2:
Minimal trauma, add 5 mL/kg/hr
Moderate trauma, add 10 mL/kg/hr
Extreme trauma, add 15 mL/kg/hr
Replace 1 mL of blood loss with 3 mL of crystalloid
Administer appropriate fluid; when in doubt give balanced electrolyte solution

Step 4
Administer appropriate colloid solution for each volume of blood lost over 15% to 20% of the animal's estimated blood volume

Step 5
Monitor vital signs and urine output. Adjust fluids to keep urine output at >0.5 mL/kg/hr

Modified from Glesecke AH, Egbert LD: Perioperative Fluid Therapy—Crystalloids. In Miller RD, editor: *Anesthesia,* ed 2, New York, Churchill Livingstone, 1986, p. 1315.

B. Consider plasma if TP < 3.5 g/dL or blood if Hct < 20%
   1. Blood loss is usually replaced with crystalloid fluids when the hematocrit is greater than 20% and total protein is greater than 3.5 g/dL
   2. Approximately 3 mL of crystalloid is used to replace 1 mL of blood loss. This ratio (3:1) may increase to as high as 8:1 in traumatized or septic animals.

C. Monitor PCV and TP for hemodilution
   1. Estimate blood loss and administer at least 3 mL of crystalloid solution for each milliliter of blood loss (unless blood transfusion is indicated; PCV < 20%)

D. Crystalloids are rapidly redistributed from the blood into the extracellular fluid, which is approximately three times larger than the blood volume

BOX 16-3

Guide to Monitoring Fluid Therapy

1. Auscultation: normal bronchovesicular lung sounds
   a. Heart rate and rhythm
   b. Mucous membrane color and capillary refill time
   c. Level of consciousness and attitude
   d. Pupillary diameter
2. Packed cell volume >20%
3. Total protein >3.5 g/dL
4. Electrolytes
   a. Sodium 145 to 155 mEq/L
   b. Chloride 95 to 110 mEq/L
   c. Potassium 4.0 to 5.0 mEq/L
   d. Calcium 8.0 to 10.0 mg/dL
5. Blood pH 7.3 to 7.45; $PaCO_2$ 35 to 45 mm Hg
6. Urine output >0.5 mL/kg/hr
7. Hemodynamics (see Box 16-1)
   a. Central venous pressure 0 to 5 cm H_2O or pulmonary capillary wedge pressure 5 to 10 mm Hg
   b. Mean arterial BP > 60-70
   c. Measures of systolic blood pressure variability (SPV) or pulse–oximeter-derived plethysmographic variability (PVI)



FIG. 16-2. Volumetric infusion pump that uses a fluid administration set.

TABLE 16-4 Characteristics and Contents of Commonly Used Crystalloids and Natural Colloids

Name	Fluid Compartment	Osmolarity (mOsm/L)	pH	Na^+ (mEq/L)	Cl^- (mEq/L)	K^+ (mEq/L)	Mg^{++} (mEq/L)	Ca^{++} mEq/L)	Dextrose (g/L)	Buffer (mEq/L)	COP (mm Hg)
					Crystalloids						
MAINTENANCE											
2.5% Dextrose in half-strength lactated Ringer's solution	Extracellular	264 (isotonic)	4.5-7.5	65.5	55	2	0	1.5	25	Lactate-14	0
REPLACEMENT											
0.9% Saline	Extracellular	308 (isotonic)	5.0	154	154	0	0	0	0	None	0
Lactated Ringer's solution	Extracellular	275 (isotonic)	6.5	130	109	4	0	3	0	Lactate-28	0
Plasmalyte-R pH 7.4*	Extracellular	294 (isotonic)	7.4	140	98	5	3	5	0	Acetate-27; Gluconate-23	0
7.0% saline	Extracellular	2396 (hypertonic)	—	1197	98	5	3	0	0	None	0
Normosol-R†	Extracellular	295 (isotonic)	5.5-7.0	140	97	5	0	0	0	Acetate-27; Gluconate-23	0
5% Dextrose in H_2O	Intracellular	252 (hypotonic)	4.0	0	0	0	0	0	50	None	0
					Natural Colloids						
Whole blood	Extracellular	300 (isotonic)	Variable	140	100	4	0	0		None	20
Frozen plasma	Extracellular	300 (isotonic)	Variable	140	110	4	0	0		None	22
Albumin	Extracellular	309 (5%; isotonic) 312 (25%; hypertonic)	6.4-7.4	130-160	130-160	<1	0	0		None	19

COP, Colloid oncotic pressure.
*Baxter Healthcare Corp.
†Abbott Laboratories.

TABLE 16-5 Characteristics and Contents of Commonly Used Synthetic Colloids and Blood Substitutes

Name	Fluid Compartment	Osmolarity (mOsm/L)	pH	Na^+ (mEq/L)	Cl^- (mEq/L)	K^+ (mEq/L)	Mg^{++} (mEq/L)	Ca^{++} mEq/L)	Dextrose (g/L)	Buffer	COP (mm Hg)
Synthetic Colloids											
6% Hetastarch	Extracellular	310 (isotonic)	5.5	154	154	0	0	0	0	None	32
6% Hetastarch in Lactated Ringer's solution (Hextend)	Extracellular	307 (isotonic)	5.9	143	124	3	0.9	5	0	Lactate	36
6% Tetrastarch; Voluven	Extracellular	308 (isotonic)	5.0	154	154	0	0	0	0	0	36
10% Pentastarch	Extracellular	326 (isotonic)	5.0	154	154	0	0	0	0	None	25
Dextran 40	Extracellular	311 (isotonic)	3.5-7.0	154	154	0	0	0	0	None	82
Dextran 70	Extracellular	310 (isotonic)	3-7	154	154	0	0	0	0	None	62
Oxypolygelatin	Extracellular	200 (hypotonic)	7.4	155	100	0	0	1	0	None	45-47
Blood Substitute (O_2 Carriers)											
Oxyglobin	Extracellular	300 (isotonic)	7.7	150	110	4.0	—	1.0	—	None	43

COP, Colloid oncotic pressure.



FIG. 16-3. Syringe infusion pump.

1. Approximately 80% to 90% of a crystalloid fluid bolus diffuses out of the vascular compartment and enters the interstitial fluid compartment within 20 minutes of completion of its administration

E. Maximum volume and rate of fluid administration during hemorrhagic hypovolemic shock therapy varies considerably; the rule of thumb is 20 to 90 mL/kg/hr

III. Hypertonic saline solution (HS; see Tables 16-3 and 16-4)

A. Normal saline solution contains 0.9% NaCl
   1. Commonly used hypertonic saline solutions contain 3%, 5%, and 7% NaCl

B. Hypertonic fluids increase vascular volume by pulling water from the interstitial fluid space into the vascular space

C. Hypertonic fluids produce acute increases in the following:
   1. Arterial BP
   2. Cardiac output
   3. Renal perfusion and diuresis
D. 7% NaCl is used as acute fluid therapy for hypotension or shock; 4 to 7 mL/kg IV
   1. HS solutions are particularly effective for improving hemodynamics in traumatized, hemorrhaged animals that have head trauma
E. Overdose of HS produces hypernatremia, hyperchloremia, and nonrespiratory acidosis; cardiac arrhythmias are a possibility

IV. Colloids (see Tables 16-3, 16-5, and 16-6)
A. Restore and maintain intravascular volume
B. Duration of effect ($t_{1/2}$) determined by molecular size; degree of substitution and pattern of substitution
C. Compared to crystalloids, colloids produce acute and lasting increases in the following:
   1. Intravascular volume
   2. Arterial BP
   3. Cardiac output
   4. Tissue perfusion and oxygen delivery
D. Small volumes (5 to 10 mL/kg IV) produce immediate increases in arterial BP and cardiac output
   1. Colloids to maintain plasma oncotic value and delay fluid extravasation
   2. Some colloids cause an autotransfusion because plasma colloid osmotic pressure (COP) is increased relative to interstitial COP
E. May prolong bleeding time

V. Blood substitutes (see Table 16-5)
A. Oxygen-carrying solutions are generally, but not always, hemoglobin-based and can be used to replace blood volume and improve tissue oxygen delivery after trauma and hemorrhage
B. Most hemoglobin-based oxygen carriers (HBOCs)
   1. Improve oxygen delivery by increasing oxygen content of the blood and expanding vascular volume
   2. Replace hemoglobin in anemic animals
C. Polymerized bovine hemoglobin in modified lactated Ringer's solution is a colloid solution that carries oxygen. Potential advantages include:

TABLE 16-6 Characteristics of Common Colloid Solutions

Colloid	Molecular Weight (range)	Molecular Weight (average)	Number Averaged Molecular Weight	Initial Volume Expansion (%)	COP (mm hg)	Osmolarity (mOsm/L)
Saline	0	0	0	20	0	310
Albumin	66,000-69,000	68,000	68,000	80	19	309 (5%)
Plasma	66,000-400,000	119,000	88,000	100	22	285
10% Dextran 40	10,000-90,000	40,000	26,000	200	82	310
6% Dextran 70	10,000-1,000,000	450,000	69,000	120	62	310
6% Hetastarch	15,000-3,400,000	70,000	41,000	100	32	310
6% Hetastarch in lactated Ringers solution (Hextend)	15,000-3,400,000	70,000	41,000	100	36	307
6% Tetrastarch; Vetstarch	110,000-150,000	130,000	60,000	130	36	308
10% Pentastarch	10,000-2,000,000	268,000	110,000	100-150	25	326

COP, Colloid oncotic pressure.

1. Immediate availability and ready to use
2. Not 2,3-diphosphoglycerate (DPG)-dependent; chloride-ion dependent
3. Stored at room temperature (2-year shelf life)
4. No typing and cross-matching (no transfusion reactions)
5. No disease transmission
6. Saves time, labor, and materials (no need for donor dog)
7. Dose range: 5 to 30 mL/kg at 10 mL/kg/hr

D. Contraindications
1. All fluids must be administered very carefully, especially colloid solutions, to animals with advanced cardiac disease (i.e., congestive heart failure) or otherwise severely impaired cardiac function or renal function
2. Fluid overload either by excessive administration or an excessively rapid rate of administration may result in heart failure and pulmonary edema; see the product's package insert for complete information

VI. Initial replacement fluid therapy

A. Maintain vascular volume and tissue perfusion by using a combination of "Recipe-" based and "Goal directed" approaches (See Box 16-1)
1. Crystalloids for maintaining hydration: 1 to 2 mL/kg/hr
2. Crystalloids can be mixed with colloids to maintain vascular volume and systolic arterial BP; lactated Ringer's solution mixed with Hextend 50:50 administered 3 to 10 mL/kg/hr for up to 3 to 4 hours

B. Restore blood volume and tissue perfusion (i.e., fluid therapy)
1. Goal: Maintain systolic arterial BP between 80 and 90 mm Hg
   a. 5 to 20 mL/kg Hextend in dogs, 5 to 10 mL/kg in cats
   b. 1 mL 23% NaCl (Baxter Corp.) mixed with 2 mL of a starch (e.g., Hextend 1:2 ratio): 3 to 5 mL/kg until effective
   c. Administer Hextend 1:1 or 1:2 for blood loss until 20 mL/kg or PCV <20%. May require the administration of a catecholamine: see below
   d. Fresh blood 5 to 20 mL/kg until effective
2. Goal: Maintain Hb concentration of greater than 7 g/dL (PCV >20%)
   a. Milliliters of donor blood = Recipient blood volume × Desired PCV − Actual PCV/PCV of donor blood

3. Goal: control hemorrhage
   a. Compression
   b. Hemostasis
   c. Surgical intervention
   d. Hemostatic agents (desmopressin 1 μg/kg subcutaneously with serial buccal mucosal bleeding time evaluation)

VII. Adjunctive/optional treatments/therapy (Table 16-7)

A. Catecholamines (only after or with fluid replacement, see Chapter 29)

TABLE 16-7 Fluid Intravenous Supplements

Supplement	Emergency Dose	(mOsm/L)	pH	Composition (mmol/L)
Calcium chloride (10%)	0.05-0.10 mL/kg slowly	2040	5.5-7.5	34 Calcium 68 Chloride
Calcium gluconate (10%)	0.5-3.0 mL/kg slowly or 60-90 mg/kg/day	680	6.0-8.2	465 Calcium Gluconate (no data)
Dextrose (50%)	500 mg/kg diluted, for immediate bolus	2530	4.2	No data
Magnesium sulphate (1 g/2 mL)	0.15-0.30 mmol/kg over 5 min	4060	5.5-7.0	4.06 Magnesium Sulphate (no data)
Mannitol (25%)	0.25-3 g/kg diluted and slowly over 30 min	1373	4.5-7.0	No data
Potassium chloride (2 mmol/mL)	0.5-1.0 mmol/kg/hr	4000	4-8	2000 Potassium 2000 Chloride
Sodium bicarbonate (8.4%), (1 mmol/mL)	0.3 × body weight (kg) × base deficit (mmol/L) or 1 mmol/L immediately	2000	7.8	1000 Sodium 1000 Bicarbonate
Tromethamine	Milliliter needed = body weight (kg) × base deficit (mmol/L) × 1.1	380	8.6	300 Tromethamine

1. Dopamine 1to10 μg/kg/min dogs; 3 to10 μg/kg/min cats; until effective or (MAP) >60 mm Hg if fluid resuscitation does not restore arterial BP
2. Dobutamine 1 to 10 μg/kg/min dogs; 1 to 5 μg/kg/min cats; until effective or MAP >60 mm Hg
3. Vasopressin: 0.4 IU/kg IV; 0.01 to 0.03 IU/kg/hr

VIII. Supportive treatment

A. Improve tissue oxygenation if hypoxemic
   1. Oxygen cage (FiO_2 >40% of air)
   2. O_2 insufflation via nasal prongs/cannula or face masks (>50 mL/kg/min)

B. Pain therapy
   1. Hydromorphone (0.05 to 0.15 mg/kg IV, intramuscular [IM] every 4 to 6 hours)
   2. Fentanyl (3 to 5 μg/kg IV loading dose followed by 3 to 10 μg/kg/hr)
   3. Lidocaine 50 μg/kg/min
   4. Ketamine 5 to 30 μg/kg/min

C. Correct acid-base and electrolyte disorders
   1. $Na^+HCO^-_3$ is generally of minimal, if any, value in animals that have gained acid (lactic acidosis)
   2. 0.5 to 1 mEq/L as needed if pH (<7.1; HCO^-_3 base excess (BE) <10 mEq/L)

D. Treat clinically relevant cardiac arrhythmias (rapid or multifocal tachycardias)
   1. Lidocaine 50 μg/kg/hr plus K^+, 0.5 mEq/kg/hr IV, when appropriate)

E. Maintain body temperature (>36.8° C)

Blood Transfusion—Major Blood Groups

I. Dogs

A. At least eight specific antigens have been identified on the dog erythrocyte
   1. Dogs that are 1.1 negative and 1.2 negative are universal donors
   2. Dog erythrocyte antigen (DEA)1, DEA2, and DEA7 have the greatest potential to induce hemolytic antibody production in recipients; dogs negative for these RBC antigens are desirable as donors
   3. Transfusion reactions related to the remaining blood-group antigens are usually clinically insignificant

4. Donor dogs should test negative for heartworms and other blood-borne diseases
5. Greyhound dogs serve are a source of blood: 70% of greyhounds have the blood type that enables them to be universal blood donors

II. Cats
- A. Three major antigens have been identified on the cat erythrocyte
  1. Transfusion reactions are rare in cats; blood typing is rarely performed
  2. RBC survival time may decrease after multiple transfusions
  3. A very low percentage of Maine coon cats are type B positive (are B negative). Maine coon, Manx and American shorthair cats, if B negative, are excellent blood donors

III. Horses
- A. At least nine specific blood group antigens have been identified
  1. Compatibility testing should be done before transfusion
     a. Blood typing
     b. Major and minor antigen agglutination
     c. Lysis cross-matching test
  2. When compatibility cannot be tested, a healthy male that has never had a transfusion is the most suitable donor

IV. Cows: at least 11 antigenic blood groups

V. Swine: at least 15 antigenic blood groups

VI. Sheep: at least 8 antigenic blood groups

Indications for Blood or Blood Substitutes

I. Restoration of oxygen-carrying capacity
- A. Anemia
  1. PCV of less than 15% to 20%; hemoglobin is less than 5 to 7 g/dL in a normally hydrated animal being prepared for surgery
  2. Nonsurgical, chronically anemic animals may not require transfusion unless PCV is less than 15 in dogs or less than 10 in cats
- B. Hemorrhage
  1. Crystalloid infusions adequately treat 15% to 30% total blood volume loss
  2. Colloids should be considered when blood loss exceeds 20% of blood volume (>15 mL/kg)

3. Whole blood or blood substitutes are necessary for replacement of more than 50% total blood volume loss
   a. Stored blood is a poor carrier of oxygen because the hemoglobin does not off-load oxygen efficiently
   b. Fresh whole blood or blood substitutes should be administered to replace acute blood loss and improve oxygen delivery to tissues

II. Restoration of blood volume after severe (>20 mL/kg) blood loss

III. Coagulation factor replacement
   A. Reduced function of platelets and coagulation factors in stored blood
   B. Choose fresh blood (stored for <12 hours) when treating coagulopathies

Collecting and Storing Blood for Transfusion

I. Obtain blood from the jugular vein or a large central vein

II. Anticoagulant solutions used
   A. Acid citrate dextrose
   B. Citrate phosphate dextrose maintains higher pH, adenosine triphosphate, and 2,3-DPG content during storage
   C. Heparin
      1. Heparin activates platelet aggregation and inhibits thrombin formation by inhibiting Factor IX activation
      2. Do not use blood collected with heparin as the anticoagulant if it has been stored longer than 48 hours

III. Plastic containers are recommended for blood collection; they are less likely to activate platelet and coagulation factors

IV. Suggested guidelines for blood storage
   A. Maintain temperature between 1° C and 6° C for the following storage times:
      1. Acid citrate dextrose anticoagulant: 21 days
      2. Citrate phosphate dextrose anticoagulant: 28 days
      3. Feline blood: 30 days
   B. At the end of those storage times, 70% to 75% RBCs are viable

Modifications of Stored Blood

I. RBCs become less deformable because of the following conditions:
   A. Hypertonicity of anticoagulant solution
   B. Decreasing erythrocyte adenosine triphosphate content
   C. Hypoxemia and metabolic acidosis

II. Erythrocyte 2,3-DPG content is decreased
   A. The oxygen dissociation curve shifts to the left; decreased oxygen is released at the tissue level
      1. Stored blood is a poor choice when increased oxygen delivery to tissues is important; blood substitute (Oxyglobin) is an alternative in these circumstances
   B. 2,3-DPG content in RBCs is restored within hours of transfusion

III. pH decreases (less than 6.5 after 3 weeks of storage); citrate anticoagulants are converted to bicarbonate within minutes by the liver; bicarbonate therapy with blood transfusion is not necessary unless inadequate liver blood flow or altered liver metabolism is suspected

IV. Platelet numbers decrease; functional platelets are nonexistent after 2 to 3 days of storage

V. Ammonia content increases; this may be detrimental for animals with impaired hepatic function

VI. Plasma potassium concentration increases because of progressive hemolysis during storage

VII. Metabolic transformations in stored blood are largely reversed during the first 24 hours after transfusion

Blood Transfusion Reactions (Box 16-4)

I. Nonhemolytic hypersensitivity reactions
   A. Activation of kallikrein-kinin system or immunoglobulin E
   B. Release of biogenic amines
   C. Clinical signs are muscle tremor, vomiting, pyrexia, hypotension, tachycardia, and urticaria

II. Hemolytic reactions
   A. Hemolysis results:
      1. Recipient antibodies interacting with incompatible antigen of donor
      2. Antibodies of a previously sensitized donor interacting with recipient antigen
   B. Immediate transfusion reactions are unlikely during a first transfusion
   C. Clinical signs usually develop within an hour after a transfusion and include hypotension, pyrexia, muscle tremor, emesis, convulsions, hemoglobinemia or hemoglobinuria, and bilirubinemia or bilirubinuria
   D. Shock, renal failure, and disseminated intravascular coagulation may ensue

BOX 16-4

Drug Doses and Route of Administration for use in Transfusion Reactions

1. STOP TRANSFUSION
2. Drugs
   - Short-acting glucocorticoids
     - Methylprednisolone succinate 30 mg/kg IV once
     - Dexamethasone sodium phosphate 4 to 6 mg/kg IV once
   - Diphenhydramine 2 mg/kg IV as required
   - Regular insulin 0.5 U/kg IV given with 50% dextrose 2 g per unit of insulin as required
   - Calcium gluconate (10% solution) 50 to 150 mg/kg IV over 20 to 30 min; discontinue if bradycardia occurs
     - Repeat if hypocalcemia persists
   - Calcium chloride (10% solution) 50 to 150 mg/kg IV over 20 to 30 min; discontinue if bradycardia occurs
     - Repeat if hypocalcemia persists
   - Furosemide 2 to 4 mg/kg IV
   - Nitroglycerin paste (2%) ¼ to 1 inch applied to skin; monitor blood pressure, may cause hypotension
   - Aspirin 10 mg/kg orally once

Modified from Hohenhaus AE, Blood Transfusions and Blood Substitutes. In DiBartola SP: *Fluid, Electrolyte, and Acid-Base Disorders in Small Animal Practice*, ed 3, Philadelphia, W.B. Saunders, 2006, p. 577.

E. Delayed transfusion reactions can occur up to 2 weeks after a transfusion
   1. The recipient mounts an immune response to incompatible erythrocytes
   2. Clinical signs include pyrexia, anorexia, jaundice, and bilirubinuria

F. Hemolysis in neonates resulting from previous sensitization of the mother (neonatal isoerythrolysis) can be avoided by preventing colostrum absorption; withhold mother's milk from the neonate for the first 48 hours of life

Nonimmunologic Adverse Transfusion Reactions

I. Sepsis: improper collection, storage, or handling may result in bacterial contamination and overgrowth
II. Transmission of infectious or parasitic diseases
III. Circulatory overload (fluid overload)
IV. Citrate toxicity

A. Citrate toxicity is rarely seen because of the rapid metabolism of citrate by the liver; it is more likely in animals with liver dysfunction or excessively rapid blood administration
B. Excessive circulating citrate causes chelation of serum ionized calcium

Plasma Transfusion

I. Indications
A. Hypoproteinemia: total protein of 4 g/dL or less; albumin of 1.5 g/dL or less
B. Failure of passive transfer; inadequate antibody absorption from colostrum
C. Thrombocytopenia: use fresh plasma
D. Coagulopathies: use fresh plasma
E. Volume expansion

II. Plasma can be stored in a conventional freezer for up to 1 year

Plasma Replacement
Donor plasma needed (mL) = Desired TP – Actual TP × Recipient PV

TP, Total protein; *PV*, plasma volume.

Routes and Volume of Fluid Administration

I. A peripheral or jugular vein

II. Intraperitoneal administration
A. Administer slowly
B. RBCs are poorly recovered into the system; approximately 40% of blood is absorbed in 24 hours

III. Medullary cavity of femur, tibia, or humerus
A. Adequate for neonatal small animals
B. Use a 20-gauge needle or a bone-marrow aspiration needle
C. 95% of the blood is absorbed within 5 minutes

IV. Rewarm stored blood to decrease viscosity and prevent hypothermia in recipients; immerse transfusion tubing in water that is maintained at a temperature of 40° C; autoagglutination occurs at higher temperatures

V. Volume of colloid or blood to be administered
A. General rule: 1 mL of colloid or blood per milliliter of blood lost
B. General rule: 2 mL of whole blood per kilogram raises the PCV by 1% (assuming there is a donor PCV of 40%)

C. The amount of blood lost in aspirated fluids

$$\text{Volume of blood in suction fluid} = \frac{\text{PCV of fluid} \times \text{Volume of fluid}}{\text{PCV of animal}}$$

D. Plasma volume needed to attain a target TP

$$\text{Amount of donor plasma needed (mL)} = \text{Desired TP} - \text{Actual TP} \times \text{Recipient plasma volume}$$

VI. Blood administration
- A. Use a fluid-administration set with a filter to remove aggregated debris
  1. Micropore filter with pore size 20 to 40 μm
  2. Cloth filter of administration set with pore size 170 μm
- B. Flush tubing before introducing blood
  1. This reduces resistance to blood flow
  2. Isotonic saline solution is the recommended fluid
  3. Lactated Ringer's or other calcium-containing solutions may recalcify blood and trigger coagulation: avoid calcium-containing fluids
  4. Dextrose solutions may cause agglutination and/or hemolysis

VII. Blood administration rate depends on clinical circumstances
- A. Administer rapidly after massive hemorrhage
- B. Blood replacement

Blood Replacement

mL of donor blood = Recipient blood volume × Desired PCV − Actual PCV/PCV of donor blood

- C. In other cases
  1. Transfuse blood slowly at 0.25 mL/kg during the first 30 minutes; observe for adverse reactions
  2. Afterward, the rule of thumb is 10 mL/kg/hr, until the desired PCV is achieved
  3. Monitor for signs of fluid overload (e.g., central venous pressure, thoracic auscultation)

17 Temperature Regulation During Anesthesia: Anesthetic-Associated Hypothermia and Hyperthermia

"If you can't make them see the light, make them feel the heat."
HARRY S. TRUMAN

Thermoregulation

I. Thermoregulation is a complex function of both central and peripheral mechanisms and is easily influenced by environmental and therapeutic manipulations. Abnormal body temperature in conscious animals is an indicator or a cause of metabolic dysfunction. Abnormal body temperature in anesthetized animals is a direct consequence of anesthetic–drug-related effects, environmental factors, and the temperature, volume, and rate of intravenous (IV) fluid administration.

A. Normal body temperature in dogs and cats is narrowly regulated ± 0.2° C around its set point but can range from 37.8° C to 39.2° C (100° F to 102.5° F)

B. Major body systems involved in thermoregulation include the central nervous system (CNS), cardiovascular system, respiratory system, musculoskeletal system, and skin

II. Thermoregulatory mechanisms

A. Cold and warm sensors are located in or beneath epidermal skin

B. Temperature signals are transmitted through A-δ and C-fibers in peripheral nerves: cold signaling is through A-δ fibers, warm signaling is through C-fibers

C. Thermal afferent nerves transmit information to the lateral spinothalamic tract

1. Each of the following contributes 20% of the thermal input:
   a. Hypothalamus
   b. Other parts of the brain
   c. Skin surface
   d. Spinal cord
   e. Deep abdominal and thoracic tissues

D. Central regulation is in the hypothalamus
   1. Efferent pathway extends from hypothalamus and ends at the α motor neurons

E. The initial response of the body to temperature variation occurs in blood vessels and is regulated by α_1- and α_2-receptors; α_2-receptors are important regulators of arterial-venous shunt vessels in peripheral tissues
   1. Vasoconstriction occurs to conserve heat
   2. Vasodilation occurs to dissipate heat

III. Heat loss mechanisms (Fig. 17-1)

A. Radiation
   1. Loss of heat to surrounding air via electromagnetic waves
   2. Radiant heat loss is proportional to the temperature difference between the animal and the environment
   3. Loss of heat through radiation accounts for approximately 60% of heat loss in humans

B. Conduction
   1. Loss of heat to objects directly in contact with the body
      a. Examples include cold operating tables, infusions of cool fluids and blood products, irrigation with cool solutions
   2. A common cause of heat loss in animals

C. Convection (facilitated conduction)
   1. Loss of body temperature to colder objects not in direct contact with the body, such as cold operating room walls,

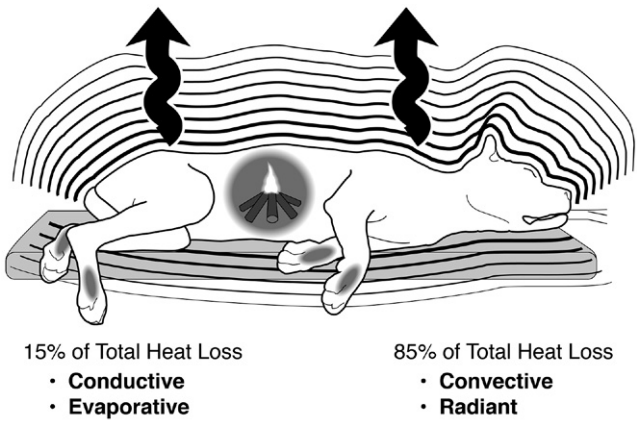


FIG. 17-1. Heat loss occurs through four mechanisms: conduction, evaporation, convection, and radiation. Evaporative and conductive heat loss can be significant in animals prepared for surgery.

or due to ventilation or induced air currents across body surfaces
2. Heat loss is a result of three factors: moving air, exposed tissue, cold ambient temperature
3. Rate of convective heat loss increases with increased airflow
4. Even warm airflow can result in convective heat loss from body surfaces

D. Evaporation
1. Loss of heat through loss of moisture from skin and lungs
a. Examples include surgically prepared areas of skin, exposed pleura or peritoneum, and the respiratory tract

IV. Hypothermia

A. Can be considered any temperature below a core body temperature of 37.8°C (100°F)
1. Occurs when heat loss exceeds heat production
2. Inadvertent hypothermia during general anesthesia is the most common perioperative thermal disturbance
a. Heat loss increases with duration of anesthesia

B. Rate of heat loss is related to species, animal's weight, animal's current temperature, and animal's percentage of body fat
1. Hypothermia is common in small animals due to their increased body surface area compared with their smaller body mass (Fig. 17-2)

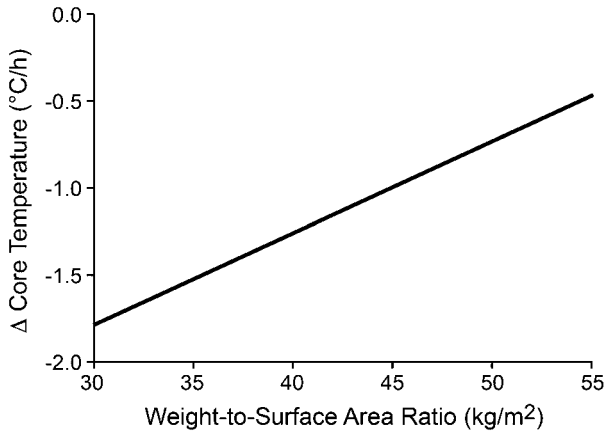


FIG. 17-2. As weight-to-surface area ratio decreases, heat loss increases. Smaller animals have more surface area compared with their body mass, so heat is lost at a more rapid rate.

2. Increased body fat is associated with a decreased rate of heat loss (Fig. 17-3)
3. Three phases are typically associated with intraoperative hypothermia (Fig. 17-4)
   a. Phase I is an initial rapid decrease in temperature
      (1) Heat redistribution decreases core body temperature

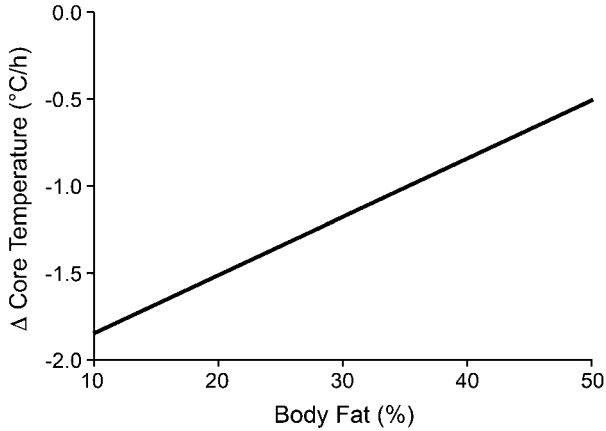


FIG. 17-3. As the percentage of body fat increases, the rate of heat loss decreases. Fat acts as insulator. Heat is lost at a more rapid rate in leaner animals.

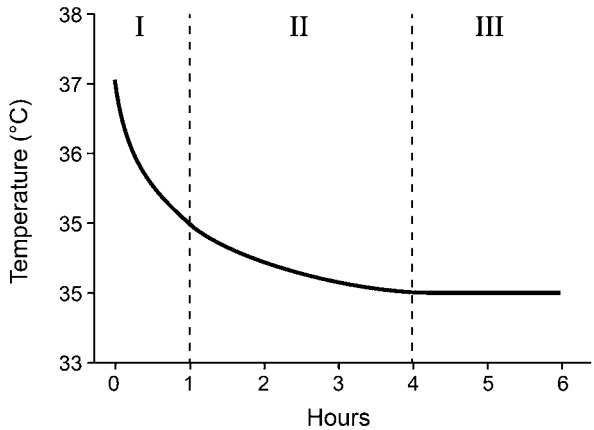


FIG. 17-4. The three phases of intraoperative hypothermia: Body heat is lost rapidly during phase I as reflected by a decrease in body temperature; phase II is a slow linear reduction in body temperature; and phase III is a thermal plateau.

(2) Core body temperatures decreases by 1°C to 1.5°C during the first hour of general anesthesia

b. Phase II is a slow linear reduction in temperature
(1) Decreases slowly over 2 to 3 hours
(2) Heat loss exceeds metabolic heat production

c. Phase III is a thermal plateau
(1) After 3 to 5 hours, core temperature stops decreasing
(2) May reflect a steady state where heat loss is equal to heat production

C. Three categories of hypothermia have been defined (Table 17-1)

1. Mild: body temperature between 32°C and 37°C (89.6°F to 98.6°F)
a. Physiologic changes: increased basal metabolic rate and oxygen (O_2) consumption, vasoconstriction, and sympathetic nervous system activation
b. Clinical signs: heat seeking behavior, shivering, tachypnea, tachycardia, diuresis
c. Effects are easily reversed by external and environmental warming strategies

TABLE 17-1 Hypothermia

Extent of Hypothermia	Temperature Range	Physiologic Changes	Clinical Signs
Mild	32°C to 37°C (89.6°F to 98.6°F)	↑ Basal metabolic rate, ↑ oxygen consumption; vasoconstriction, sympathetic nervous system activation	Heat-seeking behavior, shivering, tachypnea, tachycardia, diuresis
Moderate	28°C to 32°C (82.4°F to 89.6°F)	↓ Metabolic rate, ↓ oxygen consumption, ↓ cerebral blood flow	Muscle rigidity, mental obtundation, cardiac dysrhythmias, hypotension
Severe	< 28°C (<82.4°F)	No thermoregulation, obtundation, ↓ blood flow, cardiac irritability, respiratory depression	Bradycardia; stupor/coma; fixed, dilated pupils; loss of reflexes and pulse; hypotension; ventricular fibrillation; apnea

2. Moderate: body temperature between 28°C and 32°C (82.4°F to 89.6°F)
   a. Physiologic changes: decreased basal metabolic rate, O_2 consumption, and cerebral blood flow
   b. Clinical signs: muscle rigidity, mental obtundation, cardiac dysrhythmias, hypotension
   c. Cardiac dysrhythmias are frequent occurrences between 31°C and 32°C (87.8°F to 89.6°F)
3. Severe: body temperature less than 28°C (less than 82.4°F)
   a. Physiologic changes: complete loss of thermoregulation, obtundation, decreased blood flow, increased cardiac irritability, respiratory depression
   b. Clinical signs: bradycardia, stupor/coma, fixed and dilated pupils, loss of reflexes and pulse, hypotension, ventricular fibrillation, apnea
   c. Asystole usually occurs at or below 21°C (69.8°F)

D. Effects of hypothermia (Table 17-2; Fig. 17-5)
   1. Sympathetic activation: mediates peripheral vasoconstriction when the body temperature falls as little as 0.2°C. This is blunted during general anesthesia leading to greater and faster decreases in body temperature in anesthetized animals.

TABLE 17-2 Deleterious effect of hypothermia

System	Consequence
Immune	Possible decreased chemotaxis, phagocytosis, antibody production; oxidative killing
Hematopoietic	Hemoconcentration, cold-induced granulocytopenia, disseminated intravascular coagulation, right oxyhemoglobin shift, decreased red blood cell deformability, increased blood viscosity
Cardiac	Reduced cardiac output, depressed contractility, arrhythmias, delayed conduction, vasoconstriction
Respiratory	Falsely increased PaO_2 (if not temperature corrected), decreased respiratory rate
Renal	Decreased renal tubular function (cold diuresis)
Gastrointestinal	Elevated serum amylase
Hepatic	Reduced hepatic function
Metabolic	Falsely decreased pH (if not temperature corrected), decreased adrenal activity, decreased metabolism of lactate and citrate, hyperkalemia, delayed wound healing
Neurologic	Decreased consciousness progressing to coma, absent motor and reflex functions

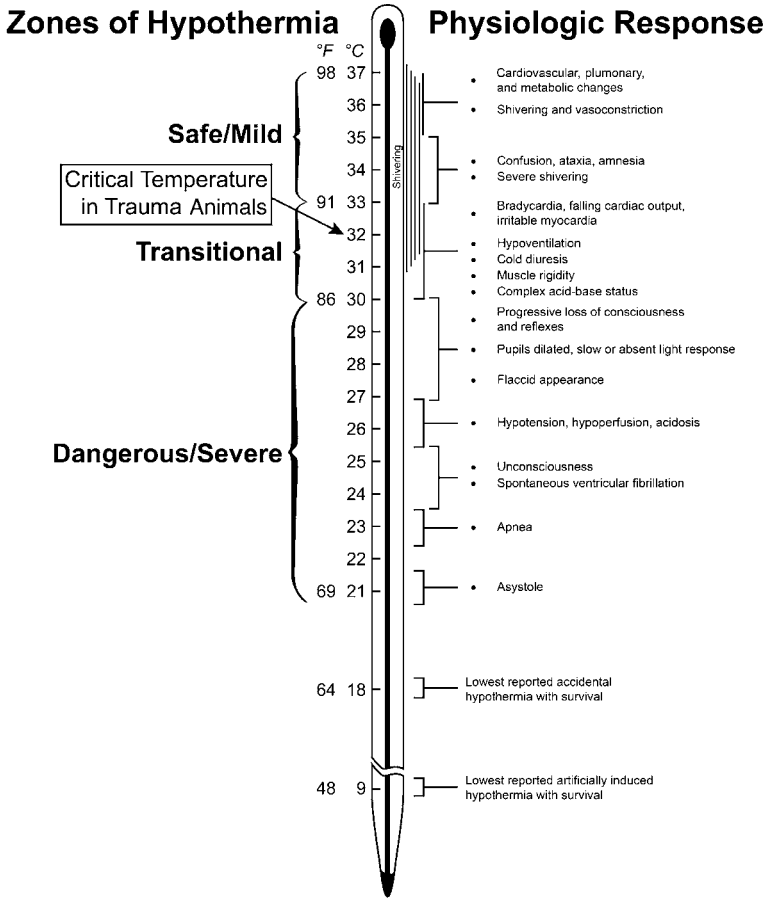


FIG. 17-5. Zones of hypothermia and the body's response to the change in temperature.

   a. Anesthetic drugs that produce vasodilation (e.g., inhalant anesthetics, propofol, acepromazine) can cause precipitous falls in body temperature
2. Pharmacokinetic alterations: depression of temperature-sensitive enzyme activity alters drug plasma concentration-effect relationship (pharmacodynamics)
   a. Hypothermia prolongs the duration and effects of many drugs, especially opioids and peripherally acting neuromuscular blocking drugs (NMBD)
3. The minimum alveolar concentration (MAC) of inhalant anesthetics decreases with decreasing body temperature

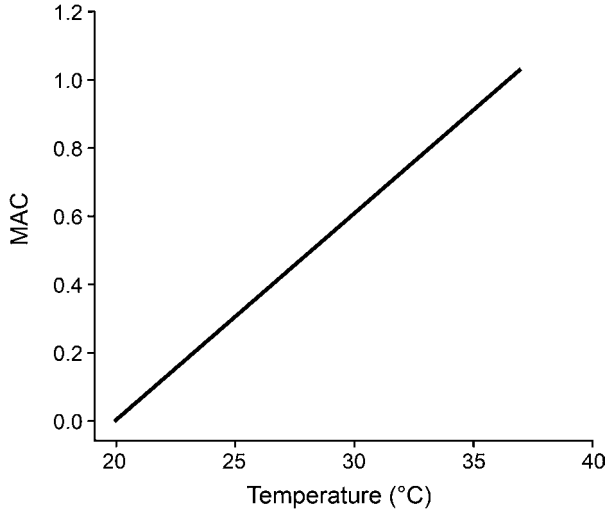


FIG. 17-6. Body temperature and minimum alveolar concentration (MAC): The MAC of potent inhalant anesthetics decreases with decreasing body temperature by approximately 4% to 5% per degree centigrade. There is complete elimination of the requirements for anesthesia at 20°C.

   a. For example, isoflurane MAC decreases approximately 5% for every degree Celsius decrease of core body temperature (Fig. 17-6)
4. Increased bleeding and blood loss: impaired coagulation occurs due to impaired platelet function, decreased clotting factor enzyme function, and increased fibrinolytic activity. Hypothermia-induced coagulation abnormalities typically resolve with a return to normothermia.
5. Oxygenation: hypothermia shifts the oxyhemoglobin dissociation curve to the left, resulting in decreased unloading of O_2 at a given PaO_2
6. Cardiac morbidity: depressed cardiac function leading to reduced blood flow and hypotension and increased cardiac irritability leading to arrhythmias
   a. Most cardiovascular stimulants including catecholamines and atropine are less effective or may not work at all
7. Wound infection: hypothermia triggers vasoconstriction resulting in decreased tissue O_2 tension and impaired immune function through neutrophil inhibition

8. Shivering: shivering increases O_2 consumption, carbon dioxide production
9. Pain: sensitivity to noxious stimuli first increases because of association with increased sympathetic nervous system activity and then decreases because of association with decreased nerve conduction
   a. Skin temperatures of less than 4°C (39.2°F) produce local analgesia
   b. Freezing of skin areas is contraindicated because of potential for frostbite

E. Common causes of hypothermia during anesthesia include:
1. Anesthetic drugs
   a. Anesthetic drugs inhibit sympathetic activation and peripheral vasoconstriction
   b. Most anesthetic drugs cause vasodilation, contributing to heat loss
2. CNS depression decreases metabolic activity and decreases the thermoregulatory set point (Fig. 17-7)
   a. Decreased central regulatory control of vasomotor tone resulting in vasodilatation

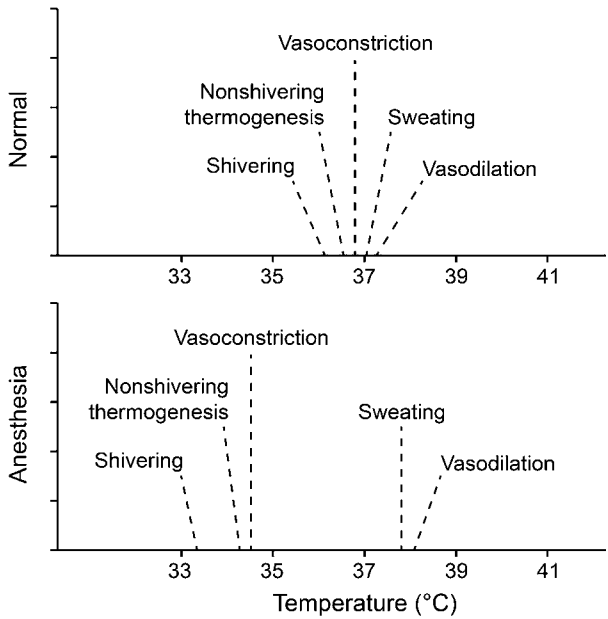


FIG. 17-7. Anesthesia alters the thermoregulatory set point. Thermoregulatory homeostasis is not stringently controlled.

3. Reduced heat production due to decreased skeletal muscle activity
4. Open body cavities during surgical procedures resulting in increased surface area for heat loss and increased evaporative and convective heat loss
5. The use of room-temperature fluids to lavage body cavities
6. Administration of room-temperature IV fluids
   a. Body temperature in humans drops by 0.25°C for every liter of room-temperature crystalloid fluids administered

V. Hyperthermia

A. Hyperthermia is defined as a core body temperature above 39°C (102.2°F)
   1. Occurs when heat production exceeds heat loss
B. Hyperthermia to temperatures between 39°C and 42°C (102.2°F to 107.6°F) require active cooling to prevent organ damage
   1. Hyperthermia to temperatures above 42°C (107.6°F) may result in permanent organ damage
C. Causes of hyperthermia
   1. Infection
   2. Inflammation
   3. Histamine release (e.g., drug administration, mast cell tumor manipulation)
   4. Drugs
      a. Opioids such as hydromorphone, morphine, and fentanyl have been associated with hyperthermia in cats
      b. Anticholinergics, inhalant anesthetics, serotonin antagonists, antipsychotic drugs, and sympathomimetic agents have been associated with hyperthermia in humans
   5. Iatrogenic: accidental overwarming
      a. Heating pads, hot environments, hot air warmers
   6. Malignant hyperthermia: a clinical syndrome observed during general anesthesia characterized by a rapidly increasing temperature (as much as 1°C over 5 minutes) and high mortality rate. The increases in temperature are due to increases in skeletal muscle metabolism.
      a. Genetic condition (autosomal recessive)
      b. Most commonly reported in swine
      c. Rarely reported in small-animal species

d. Use of anesthetic drugs including isoflurane, ketamine, and succinylcholine

D. Clinical signs of hyperthermia include: muscle rigidity, rhabdomyolysis, hyperkalemia, acidosis
   1. Treatment
      a. Active cooling: administer supplemental O_2, apply cool water or alcohol to the skin, use a fan to increase airflow across skin, administer IV fluids (room temperature)
      b. Aggressive methods of cooling should be employed with caution: cold IV fluid administration, gastric lavage with cooled fluids, cooled fluid for peritoneal lavage, cool-water enemas, or submersion in cold water
      c. Administer antipyretics (nonsteroidal anti-inflammatory drugs [NSAIDs]), muscle relaxants (e.g., diazepam, midazolam, guaifenesin), and vasodilators (acepromazine)

VI. Temperature monitoring
   A. Temperature should be routinely monitored during anesthesia
   B. Core body temperature is monitored by rectal or esophageal temperature probes or thermometers
   C. Multiple studies have concluded that prewarmed crystalloids (fluids) provide minimal if any benefit over ambient temperature fluids when administered to maintain or increase body temperature. Warmed fluids (35°C to 41°C) lose heat very rapidly and unless administered very rapidly in large volumes (>30 mL/kg of body weight/hr) provide minimal long-term effect.

VII. Rewarming strategies
   A. Drugs
      1. Antagonism of CNS depressants and opioids (Table 17-3)
         a. Opioid antagonism with naloxone
         b. Benzodiazepine antagonism with flumazenil
         c. α_2-Agonists can be antagonized by atipamezole or yohimbine
   B. Passive rewarming
      1. Passive insulation with blankets
      2. Booties, socks, or wrapped cellophane around extremities (Fig. 17-8)
   C. Active rewarming

TABLE 17-3 Drug Antagonists

Drug Type	Antagonist	Dose
Opioids	Naloxone	0.005-0.015 mg/kg IV
	Naltrexone	0.05-0.1 mg/kg SQ
α_2-Agonists	Tolazoline	0.5-5 mg/kg IV SLOW
	Yohimbine	0.1-0.3 mg/kg IV
	Yohimbine	0.3-0.5 mg/kg IM
	Atipamezole	0.05-0.1 mg/kg IM
Benzodiazepine	Flumazenil	0.02 mg/kg IV

IM, Intramuscularly; *IV,* intravenously; *SQ*, subcutaneously.



FIG. 17-8. Passive warming can be accomplished by using booties, socks, or cellophane wrapped around extremities.

1. In-circuit humidifiers placed in the inspiratory limb of a circle breathing system add heat, but are ineffective as a sole means of temperature support or for rewarming
   a. Less than 10% of metabolic heat is lost through the respiratory system
2. Circulating water blankets are associated with a less significant drop in temperature in animals under anesthesia and limit conductive heat loss (Fig. 17-9, *A,* and *B*)



FIG. 17-9. Warm-water circulating systems can be used to limit conductive heat loss (**A**). The Hallowell Heated Hard Pad (**B**) or pliable polymer blankets can be used with systems such as the Gaymar T/Pump.



FIG. 17-10. Latex gloves can be filled with water and microwaved. Caution should be used so that the heated gloves are not overheated and do not break. Gloves should be covered with a towel to prevent direct contact with animal skin.

3. Water-filled latex gloves (Fig. 17-10)
4. Forced-air blankets have resulted in significantly higher core temperatures than other methods (Fig. 17-11, *A*, and *B*)
5. Warmed IV fluids are ineffective as a means of rewarming
   a. Administrating warmed fluids has been ineffective due to rapid cooling of fluids combined with low rates of IV fluid administration
   b. Fluid line warmers should be placed near the animal for maximal effectiveness (Fig. 17-12, *A* through *D*)
6. Electrical blankets have been associated with burns and are NOT recommended
7. Thermo-controlled heating systems have been associated with less significant drop in temperature in animals under anesthesia, and may limit conductive and convective heat loss (Fig. 17-13, *A*, and *B*)
8. Extracorporeal blood warming is invasive and is impractical
9. Body cavity lavage through administration of warm fluids through an orogastric tube is invasive and is advocated only in animals with severe, life-threatening hypothermia

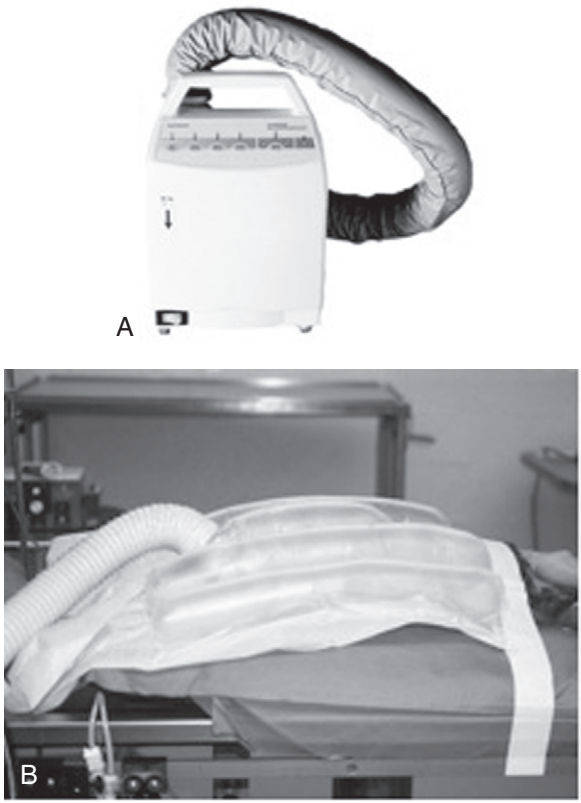


FIG. 17-11. Forced air systems such as the Gaymar Thermacare (**A**) attach to disposable plastic blankets (**B**) to cover or surround animals during surgery or in recovery.

10. Other strategies
    a. Limiting surgery/anesthesia time
    b. Using low-flow or closed-circuit anesthesia
    c. Use of specially designed circuits: "to and fro"
    d. Pre-warming
11. Effectiveness of rewarming strategies
    a. Forced air blankets and pads are associated with the greatest increases in body temperature (Fig. 17-14)
    b. Warming fluids may be a useful strategy to limit heat loss
    c. Using several strategies for rewarming may be beneficial

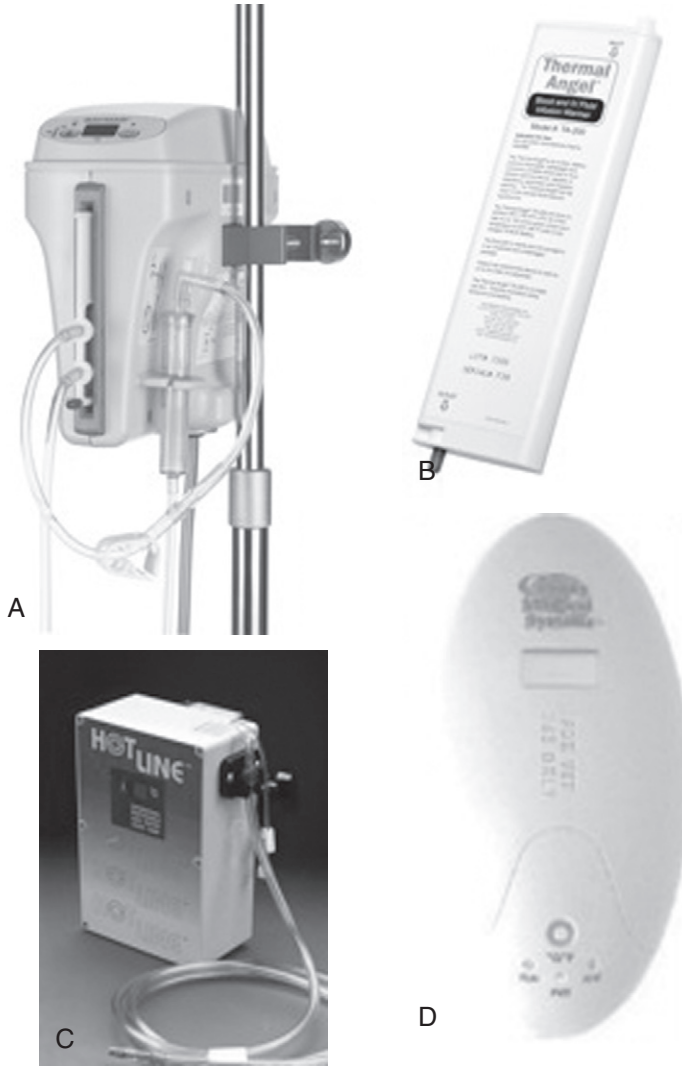


FIG. 17-12. Fluid warming systems such as the Gaymar MediTemp (**A**), the Thermal Angel (**B**), the HotLine (**C**), and the GradyVet 9500 (**D**) can be used to warm IV fluids during administration. Fluid warming is most effective when higher flow rates of fluids are administered and when the warmers are close to the site of administration.

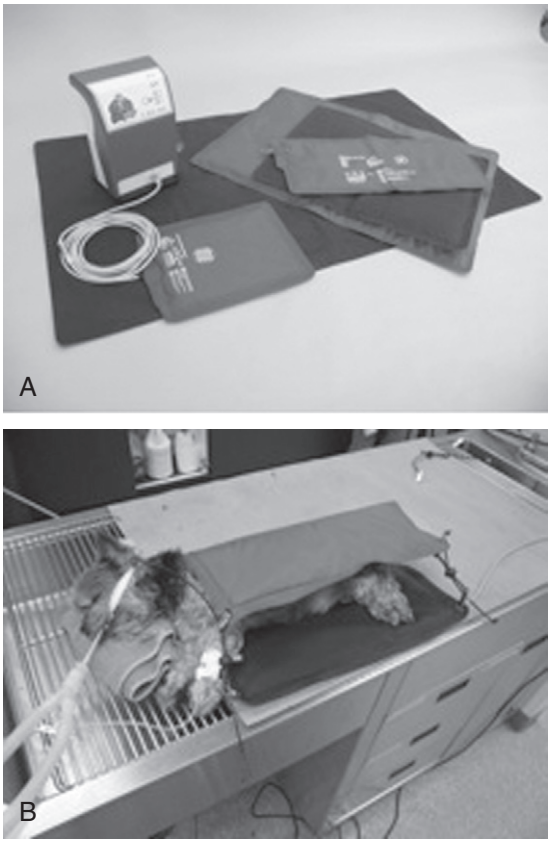


FIG. 17-13. The Hot Dog warming system (**A**) can be used to help with conductive heat loss and can also be wrapped around animals (**B**) to limit convective heat loss. This device is less likely to introduce convective contamination of superficral surgical sites.

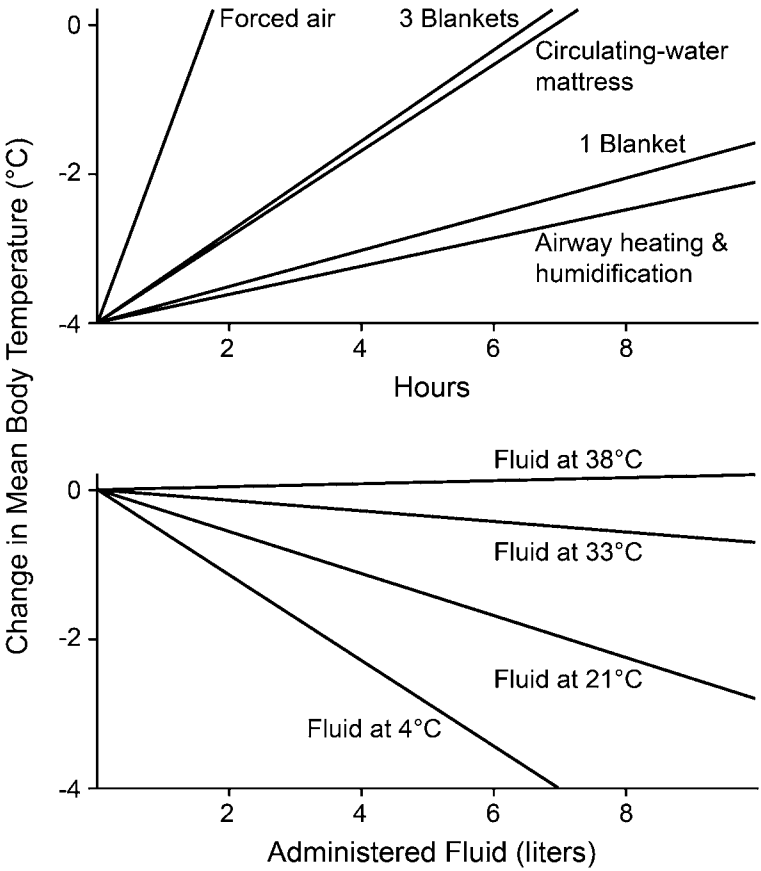


FIG. 17-14. Body temperature changes in response to heating strategies *(top)* and fluid administration *(bottom)*. Notably, warmed fluids administered at clinical rates (5 to 15 mL/kg/hr) do not help maintain body temperature.

12. After-drop phenomenon is a continued decrease in core body temperature after initiation of heat application to the skin
    a. Likely caused by the low peripheral blood flow and further peripheral vasoconstriction impeding heat transfer between the skin and body core
    b. The result of the after-drop phenomenon is that most animals will initially get colder after application of rewarming strategies

18 Pain and Pain Therapy

"Dying is nothing, but pain is a very serious matter."
HENRY JACOB BIGELOW

OVERVIEW

The definition, recognition, quantitation, and treatment of pain have become central issues in veterinary practice. This statement is particularly relevant when considering the treatment of perioperative pain. Untreated acute pain (e.g., from physical trauma, surgery) produces physiologic and emotional changes in animals that predispose them to adaptive pain states, or if untreated or severe, the potential for maladaptive (pathologic) pain states. Providing pain relief is as important as choosing the proper sedative, muscle relaxant, and injectable or inhalant anesthetic. Apprehension and stress, produced by fear, can initiate a variety of potentially deleterious neurohumoral reactions (stress response) that sensitize both the peripheral and central nervous systems to noxious stimuli (Fig. 18-1). Understanding pain pathways, the mechanism(s) responsible for pain and the action of analgesic therapies provide a rational approach to pain therapy. Recognizing and anticipating pain behaviors facilitates its prevention (preemptive analgesia) and early treatment.

General Considerations

I. Definitions

Acute pain: the sudden onset of pain that can be severe but disappears when the stimulus is removed or in a relatively short time; disappears with healing, and tends to be self-limiting

Adaptive pain: pain evoked from actual or impending tissue damage and is protective. Pain induced by environmental stimuli that limits or prevents physical contact or movement and promotes healing

Allodynia: Pain evoked by a stimulus that does not normally cause pain

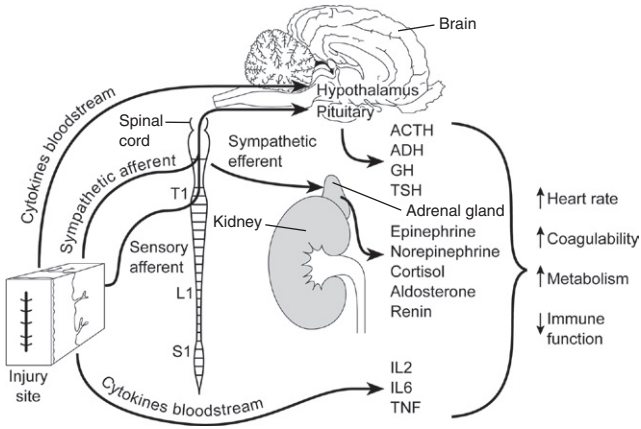


FIG. 18-1. Tissue injury causes significant hemodynamic, hematologic, metabolic, and immune-mediated responses, collectively producing a stress response. ACTH, adrenocorticotropic hormone; ADH, antidiuretic hormone; GH, growth hormone; IL1, interleukin-1; IL6, interleukin-6; L1, first lumbar vertebra; S1, first sacral vertebra; T1, first thoracic vertebra; TNF, tumor necrosis factor; TSH, thyroid-stimulating hormone.

Analgesia: Loss of sensitivity to pain

Analgesic: Any method or drug that relieves pain

Analgia: Painlessness

Breakthrough pain: A transient flare-up of pain in the chronic pain setting; can occur even when pain is being controlled by analgesic therapies

Cancer pain: Pain that can be acute, chronic, or intermittent and is related to the disease itself or to the treatment

Central sensitization: An increase in nerve excitability and responsiveness in the central nervous system, particularly the spinal cord (Fig. 18-2)

Chronic pain: Pain that lasts several weeks to months and persists beyond the expected healing time

Deep pain: Pain originating from tendons, joints, muscles, and periosteum; it is not unusual for deep pain to cause a drop in blood pressure, a slowing of the pulse, and nausea, vomiting, and sweating; can cause reflex cramping of nearby skeletal muscles

Distress: (1) A state produced when the biologic cost of stress negatively affects biologic functions critical to the animal's well-being; (2) to cause pain or suffering or to make miserable

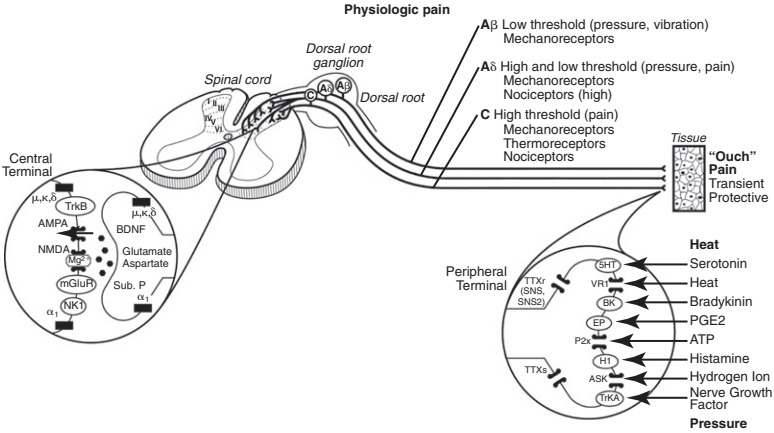


FIG. 18-2. Peripheral sensitization and central sensitization. Increased responsiveness to minimally or nonpainful stimuli (allodynia) as a result of tissue damage (peripheral sensitization) or central nervous system amplification of peripheral neural input (central sensitization). See text for additional details.

Epidural: The space above the dura mater

Hyperalgesia: An increased or exaggerated response to a stimulus that is normally painful (a heightened sense of pain) either at the site of injury (primary) or in surrounding undamaged tissue (secondary or extraterritorial). Nociceptors (pain receptors) respond to painful stimuli more vigorously and at a lower stimulus intensity

Hyperesthesia: Increased sensitivity to stimulation

Hyperpathia: A painful syndrome characterized by an increased reaction to a stimulus, especially if it is repetitive

Hypoalgesia: Decreased sensitivity to pain

Hypoesthesia: Decreased sensitivity to stimulation

Institutional Animal Care and Use Committee: A committee whose existence is required by the U.S. Department of Agriculture and the U.S. Department of Health and Human Services at institutions conducting research on animals; consists of veterinarians, practicing scientists, nonscientists, and individuals not affiliated with the institution; responsible for evaluating the institutional animal care and use programs and making recommendations to institution administrators; ultimately responsible for approving or disapproving the use of animals in research at the institution on a case-by-case basis

Interventional pain management: Action taken to prevent or alter the body's production or transmission of pain signals to the brain.

Local anesthesia: Analgesia generally limited to a specific area where the anesthetic drug is applied or injected

Major surgery: Any surgical intervention that penetrates and exposes a body cavity; any procedure that has the potential for inducing permanent physical or physiologic impairment; any procedure associated with orthopedics or extensive tissue dissection or transection

Maladaptive pain: Pain that tends to be out of all proportion to actual tissue damage and which persists long after the tissues have healed so that the pain becomes the problem

Minor surgery: Any surgical intervention that produces minimal impairment of physical or physiologic function (e.g., laparoscopy, superficial vascular cutdown, percutaneous biopsy)

Multimodal analgesia: The use of multiple drugs that act by different mechanisms to produce analgesia with the goal of producing additive or synergistic (supra-additive) effects. Multimodal drug combinations have the potential to produce greater efficacy at reduced individual drug dosages, thereby increasing safety

Myofascial pain: A syndrome of focal pain in a muscle or related tissues, associated with stiffness, muscle spasm, and decreased range of motion

Neuralgia: Pain exhibiting periodic intensification, which extends along the course of one or more nerves

Neuroleptanalgesia: Hypnosis and analgesia produced by the combination of a neuroleptic drug (i.e., tranquilizer) and an analgesic drug

Neuropathic pain: Pain that originates from injury or after injury of the peripheral or central nervous system (CNS), possibly associated with motor, sensory, or autonomic deficits

Neuroplasticity: adaptive changes in the central or peripheral nervous system caused by changes in the environment (e.g., infection, inflammation, trauma)

Nociception: The transduction, conduction, and CNS processing of nerve electrical signals generated by the stimulation of nociceptors (pain receptors). The physiologic process that leads to the perception of pain

Opioid: A pain-relieving drug that is related naturally or synthetically to morphine

Pain: An aversive sensation and feeling associated with actual or potential tissue damage

Pain threshold: The least stimulus that produces pain

Pain tolerance level: The greatest level of pain that can be tolerated

Pathologic pain: A disease state caused by damage to the nervous system (neuropathic) or by its abnormal function (dysfunctional). Pathological pain is maladaptive and usually includes peripheral sensitization, central sensitization, and hypersensitivity resulting in allodynia

Perception of pain: Only humans report and demand treatment of pain; pain in animals must be inferred by the observation of deviations from normal behavior or the development of abnormal behavior; pain may manifest itself as a limp or altered gait; withdrawal of an injured part; awkward, abnormal postures; a worried or distressed expression; looking at, licking, scratching, or kicking at the site of perceived pain; these and similar signs are the only clues a veterinarian can use to diagnose the presence and magnitude of pain; it seems likely that the presence of pain in animals is underdiagnosed and, when diagnosed, that its magnitude is underestimated

Perioperative: around (the time of) surgery; the period of time extending from when the animal enters the hospital for surgery until the time the animal is discharged

Peripheral sensitization: An increase in the activity, excitability, and responsiveness of peripheral nerve terminals (see Fig. 18-2)

Physiologic pain: The normal response (nociceptive pain; "ouch" pain) to a noxious stimulus that produces protective mechanisms causing the animal to minimize tissue damage (fight-or-flight response) or to avoid contact with external stimuli during a reparative phase (Fig. 18-3)

Preemptive analgesia: The administration of analgesic therapy before painful stimulation to prevent sensitization of neurons, or windup, with the goal of improving analgesia

Projected pain: An error in the localization of pain; occurs with superficial pain, which is normally quite accurately located; injury to a nerve containing pain pathways causes a phantom pain to be projected into the uninjured area at the origin of the pain fibers

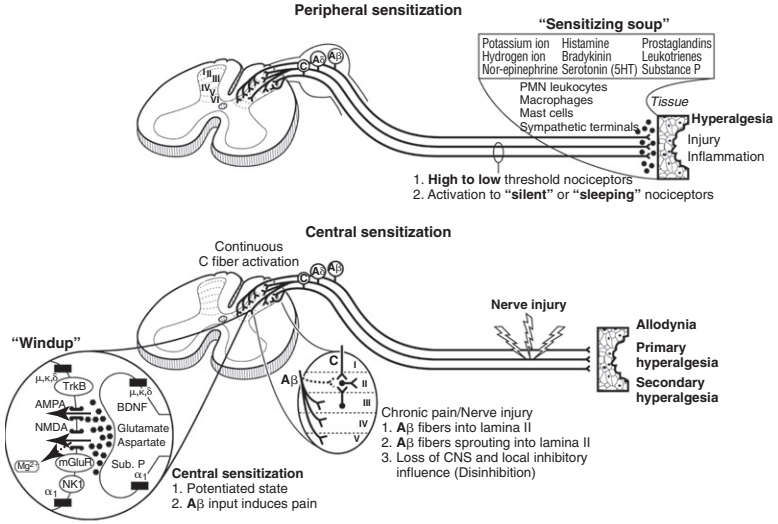


FIG. 18-3. Nociceptive, sometimes referred to as physiologic pain, is the neural process of transducing and processing noxious stimuli. Thermal, chemical, or mechanical stimuli activate receptors and are transduced to electrical signals that are transmitted to the central nervous system (CNS) by Aβ, Aδ and C nerve fibers. These electrical impulses release neurotransmitters in the dorsal horn of the spinal cord and are transduced (AMPA, NMDA, etc.) to electrical signals that are projected to the brain. Nociceptive pain is protective.

Referred pain: Pain originating in one part of the body but perceived as occurring in another; occurs as the result of the synapses in the spinal cord of visceral pain fibers with pain fibers from the skin

Regional anesthesia: The loss of sensation in part of the body caused by interruption of the sensory nerves that conduct impulses from that region of the body

Sedation: CNS depression in which the animal is awake but calm and generally uninterested in its surroundings; a term often used interchangeably with tranquilization; sufficient stimulation will arouse the animal

Somatic pain: Pain that originates from damage to bones, joint, muscle, or skin and is described by humans as localized, constant, sharp, aching, and throbbing

Stoic: Indifferent to pain or pleasure

Stress: The biologic responses of an animal to cope with a disruption or threat to homeostasis. A stressor is a physical, chemical, or emotional factor (e.g., pain, trauma, fear) to which an individual fails to make a satisfactory adaptation

and which causes physiologic tensions that may contribute to the development of disease

Subarachnoid: The space above the pia mater and below the arachnoid mater in which cerebrospinal fluid is found. A subarachnoid injection is also referred to as a spinal

Superficial or cutaneous pain: Originating on an outer surface (skin) and generally well localized; superficial pain may be sharp or acute or it may be chronic, burning, or aching; may cause an increase in pulse rate and blood pressure

Surgery: The act of incising living tissue; an operative procedure; the room or facility where an operative procedure is performed

Surgical facility: A group of interrelated rooms specifically designed for conducting surgery and for preoperative and postoperative functions associated with conducting surgery in animals

Survival/recovery surgery: A surgical procedure from which animals recover from the effects of general anesthesia and become conscious

Sympathetic mediated pain: A syndrome in which there is abnormal sympathetic nervous system activity, causing a severe debilitation and often associated with tenderness to a light touch

Tolerance: A shortened duration and decreased intensity of drug effect and/or a marked elevation in the average dose required to achieve a given effect

Tranquilization, ataraxia, neurolepsis: State of tranquility and calmness in which the animal is relaxed, reluctant to move, awake, unconcerned with its surroundings, and potentially indifferent to minor pain; sufficient stimulation will arouse the animal

Visceral pain: Originating from internal organs, visceral pain is poorly localized; small injuries may not cause pain, but diffuse foci can produce extremely severe pain; pulling and twisting of viscera, mesenteries, and ligaments can cause pain in an anesthetized animal; visceral pain can be perceived as a pain on the body surface; this error in pain localization is called referred pain; if the visceral involvement results in an inflammation that extends to an area of parietal peritoneum, pleura, or pericardium, pain fibers from these areas are also stimulated; pain fibers in the parietal peritoneum or pleura are innervated like the skin and are capable of sensing acute, highly localized pain referring to the corresponding area on

the surface of the body; visceral pain can also produce significant sympathetic activation (e.g., tachycardia, hypertension, tachypnea) and skeletal muscle spasm of the abdominal wall over the affected area; usually involves the parietal peritoneum

Windup: Temporal summation of painful stimuli in the spinal cord. Mediated by C-fibers and responsible for "second" or delayed pain (see Fig. 18-2)

II. Physiology of pain and pain pathways

A. Peripheral pain receptors

1. Mechanosensitive
   a. Stress, stretching
   b. Compression, crushing
2. Thermosensitive; involves temperature change
   a. Heat
   b. Cold
3. Chemosensitive
   a. Neurotransmitters (e.g., acetylcholine, substance P)
   b. Prostaglandins
   c. Autocoids
      (1) Bradykinin
      (2) 5-Hydroxytryptamine (5HT)
      (3) Histamine
      (4) Potassium
      (5) Proteolytic enzymes
   d. Acids (e.g., lactic acid)
   e. Cytokines
      (1) Tumor necrosis factor
      (2) Interleukin-1, 6, 8
      (3) Calcitonin gene-related peptide
   f. Leukotriene
   g. Nerve growth factor

B. Peripheral nerves (Table 18-1)

1. Myelinated nerve fibers (Aα, Aβ, Aγ, Aδ) transmit acute, accurately localized (epicritic), sharp, and rapid onset pain (see Fig. 18-3)
2. Nonmyelinated C nerve fibers transmit chronic, diffuse (protopathic), dull, burning, and aching pain (see Fig. 18-3)

C. Spinal cord pathways

1. Peripheral nerves enter the spinal cord through the dorsal roots and then ascend or descend one or two segments in Lissauer's tract

TABLE 18-1 Injectable Analgesic Drugs and Their Mechanism of Action

Drug	Mechanism of Action
Opioids (morphine, fentanyl, methadone, meperidine, hydromorphone, oxymorphone, buprenorphine, butorphanol)	Combine with opioid receptors to produce sedation, analgesia, and euphoria
α_2-Agonists (xylazine, detomidine, medetomidine, dexmedetomidine, romifidine)	Combine with α_2-receptors to produce sedation, muscle relaxation, and analgesia
Nonsteroidal antiinflammatory drugs (flunixin meglumine, phenylbutazone, aspirin, carprofen, ketoprofen, etodolac, meloxicam, deracoxib, firocoxib, robenacoxib, piroxicam)	Act centrally (CNS) on the hypothalamus; antiinflammatory and analgesic activity mediated by peripheral inhibition of prostaglandins
Local anesthetics (lidocaine, mepivacaine, bupivacaine, ropivacaine)	Block nerve transmission of electrical impulses

CNS, Central nervous system.

2. Peripheral nerves terminate in the dorsal horn gray matter (substantia gelatinosa)
3. Peripheral nerves synapse with nerves of the spinothalamic tract and are carried centrally to the following:
   a. Thalamus: somatosensory cortex
   b. Reticular activating system, which is important in activating the autonomic nervous system, limbic system, amygdala, and locus coeruleus; the following conditions can result:
      (1) Sleep arousal
      (2) Cardiopulmonary changes
      (3) Aversion reaction
      (4) Stress response
4. Spinal cord pain modulators
   a. Facilitatory
      (1) Substance P (neurokinin-1 type)
      (2) Glutamate (*N*-methyl-D-aspartate [NMDA type])
      (3) Prostanoids
      (4) Serotonin (5-HT_2)
      (5) Norepinephrine
      (6) Acetylcholine

(7) Adenosine triphosphate (ATP)
(8) BDNF (brain derived neurotrophic factor)

b. Inhibitory
(1) γ-Aminobutyric acid (GABA)
(2) Opioids
(3) α_2-Agonists
(4) Adenosine (A_1-type)
(5) Serotonin ($5\text{-}HT_1$)
(6) Norepinephrine
(7) Kainate

5. Central perception
a. Pain is inferred by observation of deviations from normal behavior, signs of stress, and physiologic responses
(1) Decreased appetite
(2) Less sleep
(3) Facial expression
(4) Altered gait
(5) Decreased or increased locomotion
(6) Reluctance to move
(7) Abnormal posture
(8) Licking, scratching
(9) Self-mutilation
(10) Decreased grooming activity
(11) Aversion
(12) Vocalization
(13) Aggression
(14) Poor body condition

b. Pain in anesthetized animals is inferred by movement or physiologic changes in response to manipulation (surgical or otherwise)
(1) Movement
(2) Trembling
(3) Increased heart rate or respiratory rate
(4) Increased arterial blood pressure
(5) Autonomic nervous system
(6) Neuroendocrine
(7) Immunology
(8) Hematology
(9) Metabolites
(10) Morphology

c. Pain or stress is inferred by increases in circulating "stress" substances

(1) Adrenocorticotrophic hormone
(2) Glucose
(3) Catecholamines (dopamine, epinephrine, norepinephrine)
(4) Beta-endorphin
(5) Leu-enkephalin
(6) Lactic acid
(7) Free fatty acids

III. Classification of pain and response to tissue injury

A. Classification of pain

1. Nociceptive (physiologic) pain (see Fig. 18-1); minimal or non–tissue-damaging stimuli that is experienced in everyday life and serves a protective role from noxious stimuli (e.g., heat, cold, pressure); nociceptive pain is adaptive, caused by stimulation of high-threshold pain receptors and serves as an early warning system (protective)
   a. Well localized
   b. Transient
   c. High threshold
2. Inflammatory pain is caused by peripheral tissue damage (e.g., crushing, surgery); inflammatory pain is adaptive and promotes tissue repair and healing (protective)
   a. Low threshold to pain (allodynia)
   b. Exaggerated response to noxious stimuli (hyperalgesia)
   c. Poorly localized (secondary hyperalgesia)
   d. Initiates peripheral and central sensitization
3. Neuropathic pain is low threshold, spontaneous pain caused by damage to the nervous system (e.g., burning, stabbing); characteristics are similar to those of inflammatory pain but is maladaptive
4. Dysfunctional pain is low threshold, spontaneous pain caused by abnormal pain processing; there may be no evidence for neural lesions or inflammation
5. Clinical pain is composed of inflammatory pain and neuropathic pain; clinical pain differs from physiologic pain because of the presence of pathologic hypersensitivity

B. Peripheral and central hypersensitization (see Fig. 18-2)

1. Peripheral sensitization results in a reduction in threshold and an increase in responsiveness of peripheral nociceptors; contributes to pain hypersensitivity and hyperalgesia

a. At the site of injury
b. In surrounding tissue

2. Central sensitization
   a. Activity-dependent increase in the excitability of spinal neurons termed spinal facilitation or windup; normal inputs produce abnormal responses
      (1) Evokes progressively greater responses in dorsal-horn, wide dynamic-range neurons
      (2) Increases the size of peripheral receptive fields
      (3) Demonstrates continual changes (field plasticity) in spatial, temporal, and threshold qualities that parallel postinjury hyperalgesia
      (4) Produces tactile allodynia
   b. Central sensitization includes windup and a prolonged phase of hyperalgesia; mediated by substance P (NK-1) and glutamate (NMDA) receptors
3. Differences between peripheral and central sensitization
   a. Peripheral sensitization is produced by low-intensity stimuli activating Aδ and C nociceptors
   b. Central sensitization is produced by normal, low-threshold Aδ sensory fibers because of changes in central processing from neural inputs

C. Pain can also cause significant delays in postoperative recovery:
1. Cardiovascular effects
   a. Increased heart rate
   b. Increased blood pressure
   c. Increased cardiac contractility and work
   d. Increased myocardial oxygen demand, reduced myocardial oxygen supply leading to potential myocardial ischemia
   e. Reduced blood flow to viscera and skin, potentially delaying wound healing
2. Respiratory effects
   a. Stimulation of respiration causing initial hyperpnea, hypocapnia, and respiratory alkalosis
   b. Diaphragmatic splinting and hypoventilation, atelectasis, hypoxia, and hypercapnia
3. Endocrine effects
   a. Catabolic and anabolic changes
   b. Decreased insulin production
   c. Fluid retention

4. Metabolic effects
   a. Increased blood glucose
5. Gastrointestinal effects
   a. Delayed gastric emptying
   b. Nausea
   c. Reduced gastrointestinal motility and ileus
6. Hemostasis
   a. Increased blood viscosity
   b. Hypercoagulability and risk of venous thrombosis
7. Behavioral effects (see IIC5a above)
   a. Quiet, depressed, and reluctant to move
   b. Guarding or protecting a specific body part
   c. Fearful
   d. Aggressive

D. Implications for pain therapy
1. Analgesia is required during surgery; intraoperative analgesia can be produced by general anesthetics, local anesthetics, and a variety of topical and systemically administered analgesic drugs (see Table 18-1)
   a. Inhalant anesthetics (desflurane, isoflurane, sevoflurane)
   b. Hypnotics (etomidate, propofol)
   c. Dissociogenic drugs (ketamine, tiletamine)
   d. Local anesthetics (bupivacaine, lidocaine, mepivacaine, ropivacaine)
   e. Opioids (buprenorphine, butorphanol, fentanyl, hydromorphone, meperidine, methadone, morphine, oxymorphone)
   f. α_2-Agonists (detomidine, dexmedetomidine, medetomidine, romifidine, xylazine)
   g. Nonsteroidal antiinflammatory drugs (NSAIDs): aspirin, carprofen, deracoxib, firocoxib, flunixin, ketoprofen, meloxicam, phenylbutazone, and piroxicam; others
2. Converting clinical pain to physiologic pain may be sufficient and is best accomplished with behavioral modifiers and antiinflammatory drugs
   a. Opioids
   b. α_2-Agonists
   c. NSAIDs
3. Prevent the establishment of pain and central sensitization (Table 18-2)

TABLE 18-2 Preemptive Analgesic Drugs and Doses*

Drug	DOSE (mg/kg) Dog	Cat	Horse	Ruminant†	Routes	Dose Interval (hr)
LOCAL ANESTHETICS						
Epidural drugs‡						
Lidocaine	1 mL/4.5-6.0 kg (2%)	1 mL/4.5-6.0 kg (2%)			—	1-2
Bupivacaine	1 mL/4.5-6.0 kg (0.75%)	1 mL/4.5-6.0 kg (0.75%)			—	4-6
Ropivacaine	0.5	0.5			—	4-6
Morphine	0.1	0.1	0.1		—	8-18
				0.5-1	—	12
Fentanyl	1-10 µg/kg	1-10 µg/kg			—	3-5
Oxymorphone	5-10 µg	5 µg			—	7-10
Butorphanol	0.25	0.25			—	2-4
Xylazine	0.1-0.4	0.1-0.4			—	3
Medetomidine	10-15 µg/kg	10-15 µg/kg			—	6-7
OPIOIDS						
Agonists						
Morphine	0.4-2.0	0.1-0.2			IV, IM	1-4
		0.1-0.3 mg/kg/hr			IV	12-48
			5-10 µg	0.5-1.0	IV	12
Meperidine	1-5	0.5-1			IV, IM	0.5-2.0
Hydromorphone	0.1-0.4	0.1-0.2			IV, IM	4-6
Oxymorphone	0.1-0.4	0.1-0.2			IV, IM	4-6
			0.001-0.020		IV	6

Continued

TABLE 18-2 Preemptive Analgesic Drugs and Doses*—cont'd

	DOSE (mg/kg)					
Drug	**Dog**	**Cat**	**Horse**	**Ruminant†**	**Routes**	**Dose Interval (hr)**
Methadone	0.5-2.0	0.02-0.10			IV, IM	2-6
Fentanyl	2-6 µg/kg	1-3 µg/kg			IV	0.2-0.5
	2-5 µg/kg/hr	1-4 µg/kg/hr			IV	12-72
	2-5 µg/kg/hr	2-5 µg/kg/hr			Transdermal patch	8-12 onset of effect; 2-4 days duration
Codeine	0.5-2.0	0.5-2.0			PO	4-6
	0.5-2.0	Contraindicated			PO with paracetamol (acetaminophen)	6-8
	0.5-2.0	0.5-2.0			SQ	
Agonist-antagonists						
Butorphanol	0.2-0.8	0.2-0.8			IV, IM	1-2
	0.1-0.3 mg/kg/hr				IV	6-12
				0.05	SQ	6
Pentazocine	0.5-4.0	0.2-1.0			IV, IM	2-4
Nalbuphine	0.5-1.0	0.4			IV, IM	1-6
Partial Agonists						
Buprenorphine	0.01-0.04	0.001-0.005			IV, IM	6-12
			0.001-0.005		IV	12
				0.005 (sheep and goats)	IM	12

α_2-Agonists					
Medetomidine	5-20 µg	0.01-0.04		IV, IM	1-4
Dexmedetomidine	5-20 µg	0.01-0.04		IV, IM	1-4
			0.01-0.02	IV	12
Xylazine	0.4-1.0	0.4-1.0		IV, SQ	1-3
			0.5-1.0	IV	12
Romifidine	0.04-0.09	0.09-0.18		IM, SQ	2-4
			0.04-0.08	IV	12
Detomidine			0.01-0.02	IV	12
OTHERS					
Tramadol	3-5	2-4		PO	6
Gabapentin	5-15	5		PO	12
Pregabalin	5-15	5	0.01-0.02	PO	12

*Refer to the text for description of local, regional, intercostal, and intrapleural nerve blocks (bupivacaine and ropivacaine 1 to 3 mg/kg, for selective nerve blocks). Lidocaine can be administered by infusion (2 to 3 mL/kg/hr [50 mg/kg/min]; IV) as an adjunct to analgesia.
†Refers to adult cattle unless otherwise noted.
‡Drug is diluted in 1 mL of 0.9% saline/5 kg; epidural opioids and local anesthetics are frequently combined (0.1 mg/kg of oxymorphone diluted in 0.75% bupivacaine to a volume of 1 mL/5 kg) to produce longer acting analgesic effects.
NOTE: Morphine (0.1 mg/kg) has been administered intra-articularly for added analgesia after stifle joint surgery in dogs.
Magnesium sulfate 6 to 8 mg/kg/hr or 5 to 15 mEq/L/hr can be administered as an adjunct to analgesia.
PO, by mouth; *IM*, intramuscular; *IV*, intravenous; *SQ*, subcutaneous.

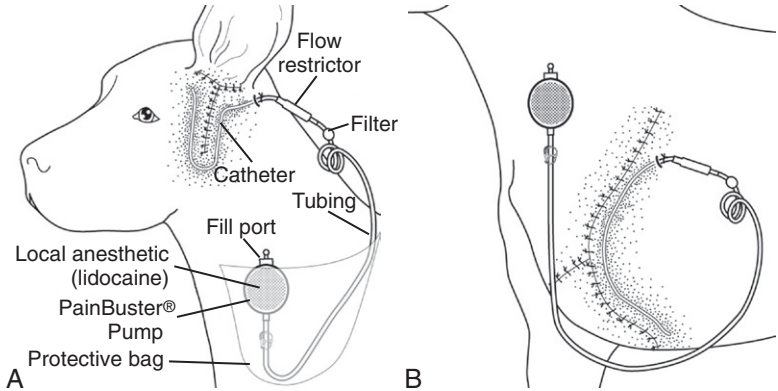


FIG. 18-4. Analgesics (local anesthetics) can be infused into painful tissue sites using flow-regulated balloon infusers or syringe infusion pumps (see Fig. 17-14).

a. Preemptive analgesia (preventative analgesia); drug combinations (e.g., opioids-tranquilizers) may be needed
b. Dose and routes of drug administration can produce select effects; intravenous (IV), intramuscular (IM), subcutaneous (SQ), and oral (PO) versus epidural, intrathecal, and site-specific administration (Fig. 18-4)

4. Multimodal analgesia
   a. Various drug combinations are known to be additive (NSAIDs-opioids) and likely synergistic (opioids-α_2-agonists) and can be used in conjunction at reduced dosages to produce improved analgesic effects, for example, the combination of morphine (1-2 μg/kg/min), lidocaine (25-50 μg/kg/min) and ketamine (10-20 μg/kg min) [MLK] can be administered to dogs and cats to reduce inhalant anesthetic requirements. Similar cocktails have been developed for other species.

Nonsteroidal Antiinflammatory Drugs (see Chapter 3; Table 3-5)

I. Reduce inflammation and produce analgesia primarily through inhibition of prostaglandin synthesis
   A. CNS actions not well characterized
   B. Inhibit the activity of cyclooxygenase (COX) peripherally
   C. The preoperative use of NSAIDs is controversial due to the renal toxicity. Animals must be normally hydrated.

(normovolemia) and have normal renal function if NSAID therapy is considered

II. Prostaglandins
- A. During inflammation, prostaglandins:
  1. Cause vasodilation
  2. Increase vascular permeability
  3. Sensitize peripheral pain receptors
  4. Chronically, new blood vessels and granulation tissue are produced
- B. Prostaglandins also help maintain tissues
  1. Protect gastric mucosa
  2. Facilitate platelet aggregation
  3. Regulate renal blood flow
- C. Currently available NSAIDs inhibit all prostaglandin formation

III. COX enzyme isoforms
- A. COX-1
  1. Responsible for basal prostaglandin production for normal homeostasis in many tissues
- B. COX-2
  1. Involved in pathologic process and found in sites of inflammation
  2. Expressed from endothelial cells, smooth muscle cells, chondrocytes, fibroblasts, monocytes, macrophages, and synovial cells
- C. Selective inhibition of certain prostaglandins primarily produced by COX-2 should allow for the therapeutic analgesic and antiinflammatory effects while greatly diminishing the unwanted side effects caused by COX-1 inhibition

19 Integrative Medicine: Acupuncture Analgesia

"Medicine is not only a science, but also the art of letting our own individuality interact with the individuality of the patient."
ALBERT SCHWEITZER

OVERVIEW

Acupuncture can be used as a complementary method of pain control during surgical procedures. Acupuncture analgesia is best achieved by electrostimulation through acupuncture needles inserted into specific acupuncture points. Various combinations of acupuncture points can be used to induce electroacupuncture analgesia (EAA) in animals. The best point combinations for producing analgesia for a particular type of surgery are unknown. Generally, analgesia is produced at sites near the points of electrostimulation. The major advantages of EAA are analgesia without producing central nervous system (CNS) or respiratory depression, bradycardia, or hypotension; good to excellent postoperative pain relief; fast postoperative recovery of appetite and gut and bladder function. The disadvantages of EAA are the need for very good restraint; a long induction period (mean time is 20 minutes) with variable degrees of analgesia; maintenance of sensations to touch, pressure, and traction; poor relaxation of abdominal muscles; and maintenance of responses to sight, sound, and smell in conscious animals.

Mechanisms of Acupuncture Analgesia

I. The mechanisms of acupuncture analgesia have been reviewed in the medical literature*

II. Modern theories attribute the effects of EAA to:
- A. Inhibition of ascending (sensory) pain signals at the peripheral, spinal ("pain inhibition gates"), and central levels
- B. Activation of descending brain-based pain inhibition mechanism, especially the midbrain and hypothalamus

*Kho H-G, Robertson EN: The mechanisms of acupuncture analgesia: review and update, *Am J Acupunct* 25(4):261-281, 1997; Schoen A, Wynn S: *Complementary and Alternative Veterinary Medicine: Principles and Practice*, St. Louis, Mosby, 1998.

III. Sensory nervous system components involved in pain sensation include Aδ and C-fibers
- A. Acupuncture points are cutaneous areas with high concentrations of nerves (particularly Aδ fibers), mast cells, capillaries, venules, and lower electrical resistance than surrounding areas
- B. Acupuncture stimuli are transmitted to the spinal cord by peripheral nerves
- C. Aδ fibers are 10 times thicker, transmit impulses 10 times faster, have a lower threshold, and are associated with milder pain sensation than C-fibers
- D. The "gate" theory suggests that Aδ fibers carry nonpainful sensations rapidly to the spinal cord where inhibitory neurons are stimulated and prevent slower pain impulses from reaching higher pain centers of conscious perception

IV. Neurotransmitters involved in acupuncture therapy and pain inhibition include:
- A. Endorphins (β-endorphin, enkephalins, dynorphin)
- B. Serotonin
- C. Norepinephrine
- D. Acetylcholine

V. Other neurotransmitters that potentiate acupuncture analgesia include:
- A. Parasympathomimetics
- B. Substance P
- C. Histamine
- D. Cyclic guanosine monophosphate

VI. Frequency of stimulation affects fibers and neurotransmitters involved in pain perception response
- A. Less than 5 Hz: Aδ fibers and enkephalin
- B. More than100 Hz: C-fibers and dynorphin
- C. More than 200 Hz: analgesia via serotonin and norepinephrine

VII. Duration of stimulation may change the mechanism of analgesia from opiate to nonopiate
- A. Segmental acupuncture analgesia usually occurs rapidly
- B. Generalized opiate effects take 20 to 40 minutes

VIII. Intensity of stimulation (voltage) traditionally is increased until muscle fasciculation is seen at 1 to 5 Hz. This produces the following conditions:
- A. General analgesia with prolonged induction
- B. Prolonged analgesia after cessation of stimulation

C. Endorphin-mediated analgesia
D. Analgesia that is reversible by naloxone

IX. High-frequency/low-intensity stimulation results in local segmental analgesia, which is irreversible by naloxone

Types of Operations Potentially Performed Under Electroacupuncture Analgesia

I. Dog
A. Cesarean section with no depressive effects on the fetus
B. Ovariohysterectomy, including toxic pyometra
C. Abdominal laparotomy
D. Gastric and intestinal surgery
E. Nephrectomy
F. Splenectomy
G. Umbilical hernioplasty
H. Removal of mammary and skin tumors
I. Ear cropping
J. Craniotomy
K. Open reduction and repair of long bone fractures

II. Horses, cattle, sheep, and pigs
A. Castration
B. Orchidopexy
C. Reposition of prolapsed uterus
D. Surgery of anal and vaginal region
E. Relief of dystocia
F. Surgery on esophagus and rumen
G. Repair of navel and umbilical hernia
H. Surgery on the bladder and urethra
I. Orthopedic surgery (bones and joints)

Equipment

I. Acupuncture needles
A. Human acupuncture needles: 29- to 34-gauge
B. Veterinary acupuncture needles: 26- to 34-gauge for large animals; 28- to 36-gauge for small animals
C. The needles are inserted at acupuncture points to the correct depth, taped or sutured firmly in position, and connected in pairs to the output socket of an acupuncture electrostimulator
D. Each pair of electrodes should be on the same side of the spinal cord. To prevent cardiac fibrillation, any one pair of leads must not cross the spine between the cervical and thoracic vertebrae

E. The leads may be alternated between needles if more needles are used than can be stimulated simultaneously

II. Acupuncture electrostimulators

A. Many electrostimulators are on the market today (www.jdsorientalhealthsupply.com)

B. The equipment is expected to have the following characteristics:

1. Strength
2. Portability
3. Battery operated
4. Have outputs for at least six to eight electrodes
5. Deliver a bipolar waveform (+) and (-) at each electrode to prevent electrolytic injury from prolonged use of monopolar waveform
6. Deliver a square or spike wave form biphasic

C. A handheld unit (Pointer Plus, M.E.D. Servi-Systems, Canada Ltd.) to locate and stimulate acupuncture and trigger points, using 10 Hz, 1 to 25 volts, and 1 to 50 milliamps, is shown in Fig. 19-1

D. A multiple electronic acupunctoscope (WQ10C, M.E.D. Servi-Systems, Canada Ltd.) is shown in Fig. 19-2. It possesses the following characteristics:

1. It detects acupuncture and auricular points
2. It stimulates three pairs of acupuncture needles for acupuncture analgesia and therapy



FIG. 19-1. Acupuncture point locator. The Pointer Plus is a handheld unit for locating and stimulating acupuncture points.

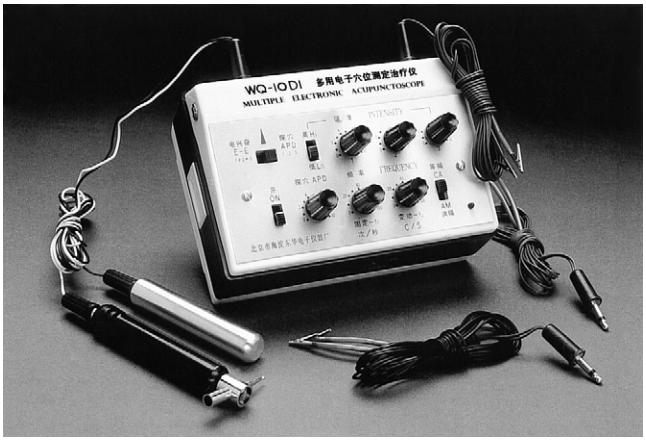


FIG. 19-2. An electronic acupunctoscope facilitates locating and stimulating acupuncture points percutaneously.

3. The frequency can be varied between 1 and 1000 Hz
4. It has a constant amplitude and amplitude modulation switch
5. It operates on 9-volt batteries

Restraint

I. Technique in small animals
- A. Small animals are generally restrained in lateral, dorsal, or ventral recumbency
- B. Dogs are given a sedative/analgesic and small doses of general anesthetics
- C. The animal's elbows and hocks are tied with bandages and secured to the operation table
- D. A muzzle may be over the dog's jaws to prevent biting (Fig. 19-3)
- E. The owner or attendant should comfort and speak to the dog from time to time during surgery

II. Technique in large animals
- A. Electroacupuncture may be performed in horses and cattle restrained in the standing position or in dorsal, lateral, or ventral recumbency
- B. For a standing animal, usual methods for restraint (stock, chute, cattle crate) as applied for surgery under local anesthesia may be used

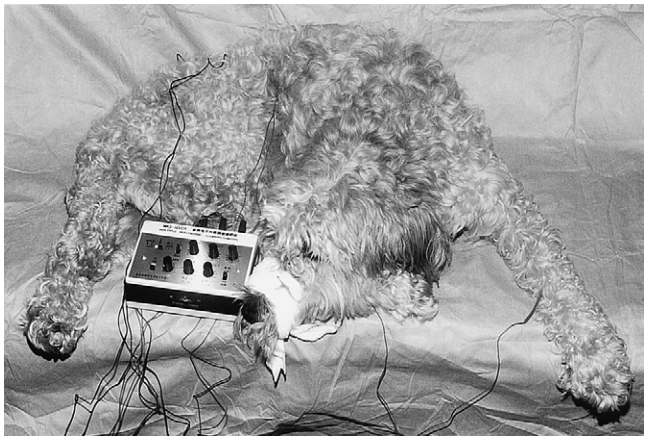


FIG. 19-3. Some animals require sedation or mild restraint during electroacupuncture stimulation.

C. Nervous animals may be given a sedative/analgesic intravenously
D. Recumbency may be induced with a short-acting, intravenous anesthetic
E. Recumbent animals should be securely restrained with ropes
F. The operator should keep noise and movement to a minimum

Selecting Acupuncture Points

I. General statements
A. Point combinations for producing analgesia sufficient for surgery vary with the operative site and the preference and experience of the surgeon
B. Points are generally chosen based on the channel (meridian) theory of human acupuncture
C. Acupuncture points in animals have the same name and code as in humans and are transposed from human acupuncture anatomy
D. Channels have a superficial course (from the first to the last point on the channel), a deep course (going to the organ of the channel), and a collateral course (linking to interior and exterior parts of the body). This may explain why a Liver point is used for operation of the eye, a Heart point for operation of the tongue, and a Kidney point for operation of the ear and bone.

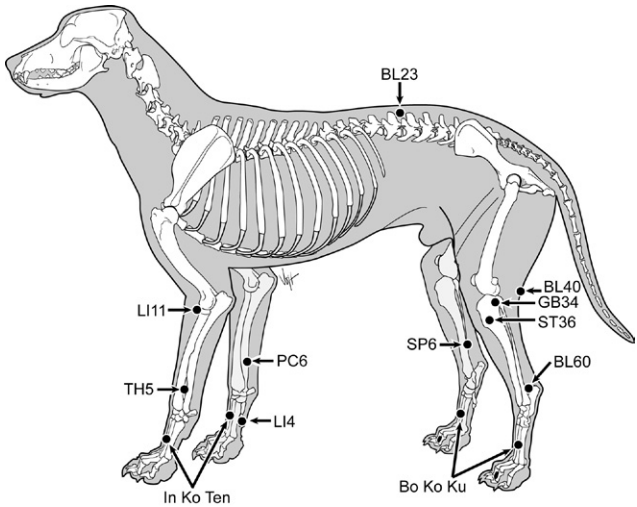


FIG. 19-4. Location of various acupuncture points to induce analgesia in dogs.

II. Acupuncture point selection in the dog. In general, the following points bilateral of the spine are chosen:
- A. For surgery in all areas: BL 23 +/or SP 6; LI 11 + Japanese point In Ko Ten; ST 36 + Japanese point Bo Ko Ku
- B. For surgery on the head, neck, thorax, and front limb: PC 6 + TH 5
- C. For surgery on the abdomen and hind limbs: SP 6 + ST 36 and paraincisional for ovariohysterectomy
- D. For surgery on high-risk dogs: LI 4 + LI 11 + SP 6 + ST 36
- E. For back surgery: BL 23 + BL 40 + BL 60 + ST 36 + GB 34

III. Anatomic location of acupuncture points in dogs
- A. Fig. 19-4 illustrates the location of the various acupuncture points for dogs
- B. The International Veterinary Acupuncture Society describes the abbreviation and location of these points as follows:
  1. LI 4 (large intestine point 4): between the first and second metacarpal bones, approximately in the middle of the second metacarpal bone on the radial side
  2. LI 11 (large intestine point 11): at the end of the lateral cubital crease, halfway between the biceps tendon and the lateral epicondyle of the humerus, with the elbow flexed

3. PC 6 (pericardium point 6): at two ribs' width above the transverse crease of the carpus between the tendons of the flexor digitorum superficialis and flexor carpi radialis
4. TH 5 (triple Heater point 5): at two ribs' width above the carpus, on the cranial aspect of the interosseous space between the radius and ulna
5. In Ko Ten: between metacarpal bones 2 and 3
6. BL 23 (bladder point 23): at one to two ribs' width lateral to the caudal border of the spinous process of the second lumbar vertebra
7. ST 36 (stomach point 36): at one finger's width from the anterior crest of the tibia, in the belly of the medial tibialis cranialis
8. GB 34 (gallbladder point 34): in the depression anterior and distal to the head of the fibula
9. BL 40 (bladder point 40): in the center of the popliteal crease
10. SP 6 (spleen point 6): at three ribs' width directly above the tip of the medial malleolus, on the posterior border of the tibia
11. BL 60 (bladder point 60): in the depression between the lateral malleolus and tendon calcaneus, level with the tip of the lateral malleolus
12. Bo Ko Ku: between metatarsal bones 2 and 3

C. The needle penetrates completely from TH 5 to PC 6 between the radius and ulna of both limbs

D. The needle may penetrate completely through the limb at ST 36 and SP 6 of both hindlimbs

IV. Acupuncture point selection in horses (Fig. 19-5, *A,* and *B*) and cattle (Fig. 19-6)

A. For abdominal surgery: LU 1 (lung point 1) + TH 8 (triple heater point 8)

1. Technique: one needle is inserted in LU 1 (caudal to the shoulder in the second intercostal space) for a depth of 3 to 5 cm (positive pole). A second needle is inserted at TH 8 (about one hand's width ventral to the elbow joint, on the lateral side) and is advanced ventromedially caudal to the radius/ulna to reach PC 4.5, subcutaneously dorsal to the "chestnut" (negative pole). A third needle is inserted at small intestine point 10 (SI 10, approximately on the caudal border of the deltoids and between the long and lateral heads of the triceps brachii). A fourth needle is

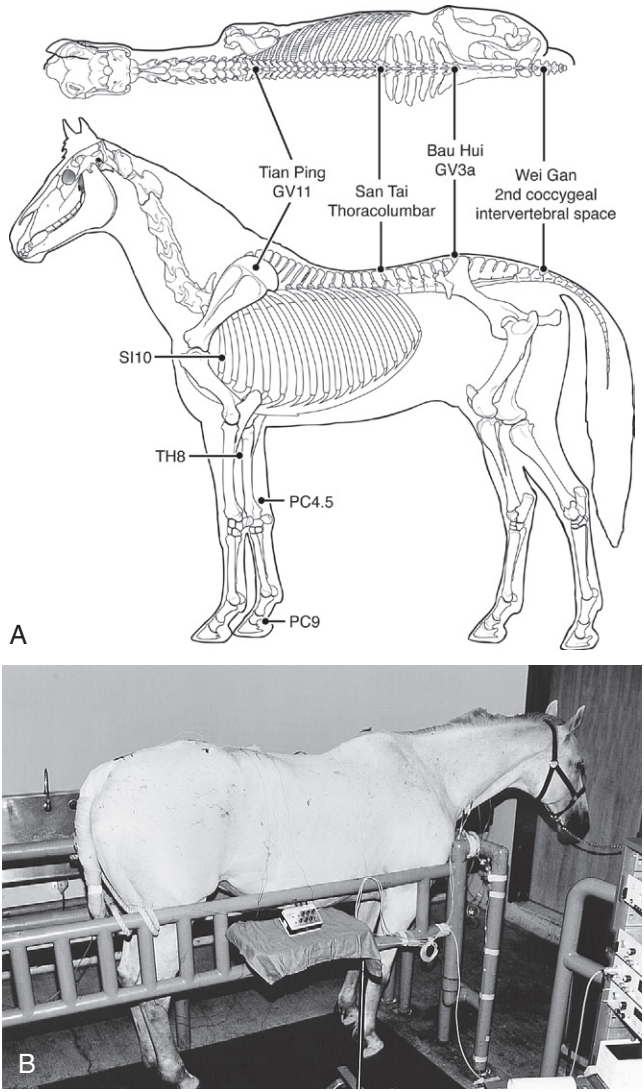


FIG. 19-5. A, Location of various acupuncture points to induce analgesia in horses. **B**, Percutaneous electrical nerve stimulation of various acupuncture points in a sedated 560-kg thoroughbred mare (detomidine 5 mg intramuscularly).

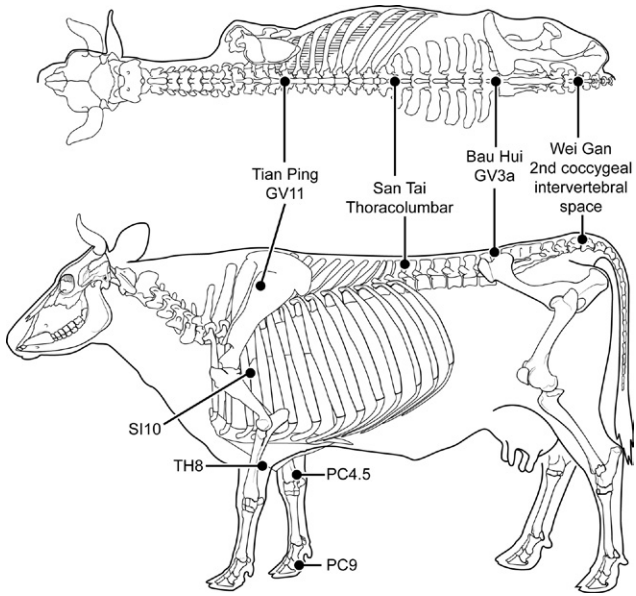


FIG. 19-6. Location of various acupuncture points to induce analgesia in cattle.

inserted in the center depression between the bulbs of the heel on the forelimb.

B. For abdominal, vaginal, and hindlimb surgery: Bai Hui (main point) + Wei Gan (secondary point) + San Tai (tertiary point) + Tian Ping (minor point) + added points on or near the spinal nerves supplying the surgical site
   1. Technique: one needle is inserted in acupuncture point Bai Hui (GV 3a point) at the dorsal midline of the lumbosacral space, 3 to 5 cm deep. A second needle is inserted in Wei Gan (at the dorsal midline of the second coccygeal intervertebral space), 1 to 1.5 cm deep. A third needle is inserted in San Tai (at the dorsal midline of the thoracolumbar intervertebral space), 2 to 4 cm deep. A fourth needle is inserted at Tian Ping (at the dorsal midline of the fourth or fifth thoracic intervertebral space, GV 11 point) and advanced cranioventrally 6 to 8 cm.

V. Acupuncture point selection in pigs

A. The Akita Veterinary Acupuncture Research Unit in Japan tested many point combinations in pigs, including LU 1 and TH 8 penetrating to PC 4.5

B. The most effective points for producing hypoalgesia are located in the midline of the thoracolumbar space (point Tian Ping) and lumbosacral spaces (Bai Hui) penetrating almost to the dura mater spinalis

Needle Placement

I. The needles are inserted deeply into the acupuncture points
   A. The points are palpated at precise anatomic landmarks
   B. Point finders (see Figs. 19-1 and 19-2) are helpful in localizing acupuncture points

II. The needles are taped or sutured in position to prevent dislodgment

Electroacupuncture Stimulation (EAA)

I. Voltage, current, frequency
   A. The power controls of the stimulator are set at zero
   B. The pairs of needles are attached to each circuit of the electrostimulator with alligator clips
   C. The power switch is turned on and the electrical stimulation frequency is set at 2 to 15 Hz
   D. The output voltage is increased slowly until the needles begin to twitch in time with the frequency of the stimulator at 2 to 15 Hz
   E. At higher frequencies (more than 15 Hz), the muscle goes into local spasm, and the needle vibration is not obvious
   F. The output voltage from each control is first increased to maximum tolerance of anesthesia mode, dense-disperse waveform
   G. The output is then reduced to a level the animal can tolerate without obvious discomfort or pain (e.g., restlessness, struggling, vocalization)

II. Onset and duration of hypoalgesia
   A. Induction time for hypoalgesia ranges from 10 to 40 minutes; 20 minutes is the duration most commonly reported
   B. The surgery site is tested for analgesia by grasping the skin with toothed forceps or clamps or pricking the skin with needles or pins every 5 minutes after the onset of electrical stimulation
   C. The electroacupuncture stimulation is continued during the entire surgery
   D. Inadequate or excessive electroacupuncture stimulus produces little or no analgesia

Advantages of Electroacupuncture Stimulation

I. EAA can induce hypoalgesia sufficient for surgery
- A. It can be used in "balanced anesthesia" to greatly reduce the dose of sedatives/analgesic and anesthetic drugs
- B. It is advantageous in cesarean sections because it has no depressive effects on the fetus
- C. It is suitable for animals that are in shock, debilitated, or toxic

II. EAA is suitable for prolonged surgery (up to 10 hours)
- A. Autonomic functions remain stable

III. When compared with general anesthesia:
- A. The technique is relatively simple and inexpensive
- B. There is less hemorrhage
- C. Postoperative recovery of appetite and gastrointestinal and bladder function are faster
- D. Postoperative healing is faster; attributable to no chemical interference with wound healing
- E. Postoperative infection is less
- F. Postoperative pain is reduced

Disadvantages of Electroacupuncture Stimulation

I. An induction period of 10 to 40 minutes (average is 20 minutes) is necessary

II. To facilitate surgery, sedatives and anesthetics are needed in 50% to 95% of cases

III. Intrathoracic surgery cannot be performed

IV. Physical restraint is necessary
- A. The amount of restraint needed depends on the skill of the surgeon and tolerance of the animal

V. Muscle relaxation may be inadequate
- A. Poor relaxation of abdominal muscles can cause "ballooning" of viscera

VI. All sensory inputs except pain are present
- A. Manipulation of viscera and organs or traction of mesentery can induce nausea, vomiting, and shock

VII. Certain body regions are more sensitive to pain than others
- A. The skin, serosa (peritoneum, pleura), periosteum, and nerves are very sensitive
- B. Incision of such organs requires the frequency and output voltage to be increased to counteract the pain
- C. The success rate for intestinal surgery is higher than for limb surgery

VIII. Pain thresholds vary among species
- A. Cattle and sheep are the most tolerant, followed by dogs, pigs, and horses

IX. Temperaments vary among species
- A. Nervous animals may be tolerant but are easily frightened and difficult to restrain, even with good analgesia

Acupuncture Supplies

M.E.D. Servi-Systems
8 Sweetnam Drive
Stittsville, Ontario
Canada K2S 1G2
1-800-267-6868 (Canada and United States)
1-613-836-3004 (worldwide)
1-613-831-0240 (fax)

Lhasa OMS, Inc.
230 Libbey Parkway
Weymouth, Massachusetts 02189
1-800-722-8775
1-781-340-1071
1-781-335-5779 (fax)
www.lhasaoms.com/

Anesthetic Procedures and Techniques in Dogs

20

"If dogs could talk it would take a lot of the fun out of owning one."
ANDY ROONEY

OVERVIEW

Anesthetic procedures and techniques for dogs are designed to safely, effectively, and economically produce calming, sedation, analgesia, and unconsciousness. Techniques using single drugs have largely been abandoned in favor of techniques that combine drugs from different classes in reduced doses, theoretically reducing unwanted side effects and toxicity. The advantage of combination drug therapy over single-drug therapy is a more controlled anesthetic state by manipulation of hypnosis, analgesia, and muscle relaxation. Combination drug therapy requires a comprehensive knowledge of the pharmacology of anesthetic drugs, their interactions, and potential side effects.

General Considerations

I. A variety of anesthetic procedures and techniques can be used to safely produce chemical restraint and anesthesia in dogs. Local anesthetic techniques (see Chapter 7) should be considered to augment analgesia.

II. The choice of anesthetic regimen is influenced by the following characteristics:
- A. Breed and size (weight)
- B. Temperament
- C. Health and physical condition
- D. Procedure (medical; surgical)
- E. Anticipated duration of anesthesia
- F. The familiarity of personnel with the drugs being used
- G. Concurrent medication
- H. Available assistance

III. Whenever possible, drugs that are reversible should be used

IV. Endotracheal intubation should be performed whenever possible to ensure a patent airway

V. Careful monitoring is mandatory to recognize and treat untoward drug effects
VI. Food and water should be withheld for approximately 4 to 6 hours before surgery, except in very small, very young, or diseased dogs

Preanesthetic Evaluations (See Chapter 2)

I. Review history and current drug therapy
II. Perform a physical examination
III. Review available laboratory data
IV. Formulate a specific anesthetic plan (Fig. 20-1)
  A. Determine whether additional preoperative tests are needed
  B. Choose appropriate drugs
V. Intravenous (IV) catheter placement is recommended
  A. To ensure vascular access
  B. Before induction to anesthesia
VI. Gather appropriate equipment and supplies
  A. Mouth gag or speculum
  B. Endotracheal tube (see Chapter 11)
    1. Select diameter of cuffed endotracheal tube based on the dog's size, breed, and procedure; brachycephalic breeds usually have smaller-diameter trachea (Table 20-1); a reinforced tube (kink resistant) should be used for procedures that may require severe curvature of the neck (e.g., ophthalmic surgeries, cerebrospinal fluid tap)
    2. Check cuff for leaks by inflating with air; deflate before intubation
    3. Use a stylet for small-diameter, endotracheal tubes, and reinforced tubes

TABLE 20-1 Endotracheal Tube Size for Dogs

Body Weight (kg)	Tube Size, mm (Inner Diameter)
2	5
4	6
7	7
9	8
12	8
14	9
20	10
30	12
40	14

PREANESTHETIC EVALUATION

ANESTHETIST:_____
DATE:_____
CLINICIAN:_____
WARD/CAGE OR STALL #:_____

PROCEDURE: .....

BODY WEIGHT: ..... **AGE:** .....

TEMPERAMENT:

OBJECTIVE FINDINGS
Temp_____ Pulse_____ Resp._____
Cardiac auscultation_____
Pulse quality _____
Mucous membrane color_____
Capillary refill time_____
Respiratory auscultation _____

ASSESSMENT: Physical status I II III IV V E
Reasons:

CBC
WBC_____ TP_____ PCV_____
Fibrinogen _____
SERUM CHEMISTRIES
BUN_____ GLUCOSE_____
AST(SGOT)_____
ALT(SGPT)_____
URINE SPECIFIC GRAVITY_____
OTHER RESULTS _____
PRIOR ANESTHESIA _____

COMPLICATIONS ANTICIPATED pre op, intra op, post op: consider age , body wt., breed, position, surgical procedure, physical status.

Plan Anesthesia regimen (include reasons as related to this animal)
(Include premeds, induction agent, inhalation agent, O_2 flow rate, post op analgesics)

DRUG	ROUTE	DOSE/#	MG	ML	REASONS OR JUSTIFICATION

MONITORING: Esophageal stethoscope, Doppler, ECG, Temp. Probe, Blood gas, Arterial Line, Other_____

IV FLUID TYPE_____ Dose: MLS/HR_____ DROPS/MIN_____

ADMINISTRATION SET: MINI DRIP (60 drops/ml) MAXI DRIP (10 drops/ml)

Approved_____

FIG. 20-1. A preanesthetic evaluation and anesthetic plan should be individually developed for each animal.

4. Use an uncuffed endotracheal tube in very small dogs (Fig. 20-2)
5. Use a small amount of sterile lubricant

C. Laryngoscope (Fig. 20-3)
1. Aids intubation by allowing visualization, illumination, and manipulation of tongue and laryngeal structures
2. May be optional, depending on dog's anatomy and size



FIG. 20-2. A tapered uncuffed endotracheal tube (Cole catheter) for intubating smaller animals.



FIG. 20-3. A laryngoscope facilitates visualization and illumination for orotracheal intubation.

D. Anesthetic machine and breathing system
   1. Size and type of system determined by dog's size
      a. Use a small-animal anesthetic machine (adult human anesthetic system) for dogs
         (1) Use a circle system for dogs weighing more than 3 kg

(2) Use a nonrebreathing system for dogs weighing less than 3 kg

2. Rebreathing bag should be approximately five times the tidal volume. Tidal volume (V_T) is 10 to 15 mL/kg of body weight (e.g., 5 kg × 10 mL/kg = 50 mL V_T)
3. Refill carbon dioxide absorbent canister if material is exhausted (discolored or dry)
4. Evaluate anesthetic system for possible malfunctions (see Chapter 12)
   a. Fill vaporizer and check operation
   b. Turn on flowmeters and check for free movement of indicator balls or slides
   c. Close pressure relief valve and pressurize the system using oxygen flush valve to 20 to 30 cm water and maintain for 15 seconds; check for leaks (Fig. 20-4)
5. Connect the waste gas scavenging system to the anesthetic circle or nonrebreathing system

E. Fresh gases
1. Oxygen
   a. Connect to "house" oxygen system, if present
   b. Attach smaller (E) tanks to machine; change oxygen tank if pressure gauge reads less than 500 pounds per square inch (psi)
2. Nitrous oxide (used to produce analgesia)
   a. Optional
   b. Change tank if pressure gauge reads less than 750 psi

F. IV administration supplies
1. IV catheter (16- to 23-gauge)
2. Appropriate IV fluids
3. Fluid administration set (standard set 10 drops/mL, pediatric 60 drops/mL). Use 60 drop/mL on dogs less than 5 kg. Administer at 5 to 10 mL/kg/hr.
4. Fluid infusion pump (Fig. 20-5)

G. Drugs
1. Calculate appropriate drug dose and volume
2. Draw drugs into labeled syringes

H. Monitoring equipment (see Chapter 14)
1. Electrocardiograph
2. Doppler with sphygmomanometer or oscillometric blood pressure monitor
3. Pulse oximeter



FIG. 20-4. "Leak test": Escape of gas from around the endotracheal tube can be eliminated by inflating the endotracheal tube cuff (right hand) until no gas escapes from the mouth during rebreathing bag compression (left hand) to 20 to 25 cm H_2O.

4. Thermometer
5. Esophageal stethoscope
6. End-tidal gas monitoring (oxygen, carbon dioxide, inhalant)

I. Ancillary supplies
1. Gauze sponges (4 by 4 inch)
2. Adhesive tape
3. Roll gauze to secure endotracheal tube
4. Flashlight

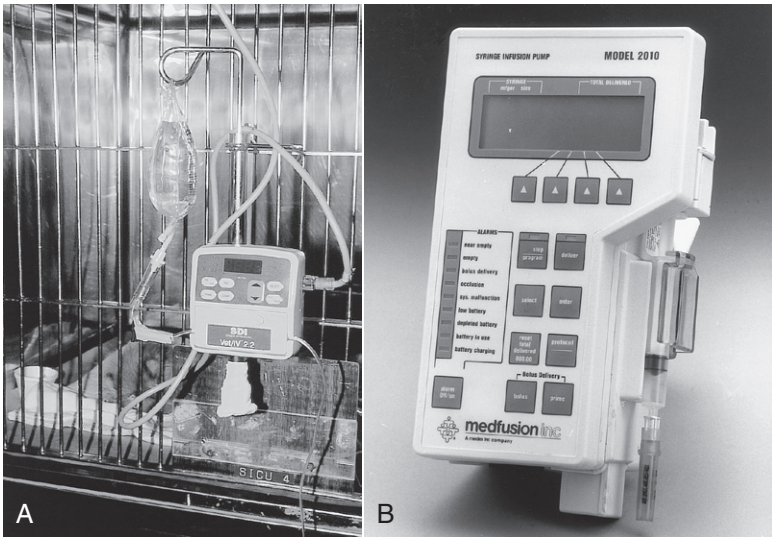


FIG. 20-5. A, Example of a fluid infusion pump. **B,** A syringe infusion pump provides extremely accurate fluid administration and is frequently used for drug infusion.

Preanesthetic Medication (See Chapter 3)

I. Choice of drug determined by the dog's preoperative condition and any other special considerations pertinent to the procedure

II. Drugs given intramuscularly (IM) or subcutaneously (SQ) should be administered 10 to 20 minutes before IV catheterization and induction

III. Drugs used as premedications

A. Anticholinergics

1. Atropine 20 to 40 µg/kg IM, IV, or SQ
2. Glycopyrrolate 5 to 10 µg/kg IM, IV, or SQ

B. Tranquilizers

1. Acepromazine 0.02 to 0.10 mg/kg IM, maximum total dose 3 mg; decrease dose by 50% when given IV
2. Diazepam or midazolam 0.2 to 0.4 mg/kg IV, maximum total dose 5 mg; usually administered in conjunction with opioids; a single-drug use is recommended for old or depressed dogs; young and healthy dogs may become excited (release of suppressed behavior); midazolam is absorbed well when administered IM

C. Opioids (frequently used with tranquilizers)

1. Morphine 0.1 to 0.3 mg/kg IM
   a. Epidural morphine (0.1 mg/kg/day with 0.9% NaCl to a volume of 1 mL/5 kg)
2. Hydromorphone 0.05 to 0.10 mg/kg IM
3. Oxymorphone 0.1 to 0.3 mg/kg IM
4. Methadone 0.2 to 0.6 mg/kg IM
5. Buprenorphine 5 to 20 μg/kg IM
6. Butorphanol 0.2 to 0.4 mg/kg IM

D. α_2-Agonists
1. Xylazine 0.2 to 1.0 mg/kg IM or IV (low end)
2. Medetomidine 5 to 20 μg/kg IM or IV
3. Dexmedetomidine 2 to 10 μg/kg IM or IV
4. Romifidine 20 to 40 μg/kg IM or IV

E. Tiletamine/zolazepam (Telazol) 2 to 10 mg/kg IM or IV
1. Vicious or mean dogs: Add 4 mL of 100 mg/mL ketamine and 1 mL of 100 mg/mL xylazine or 0.5 mg/mL dexmedetomidine to a 5 mL bottle of Telazol
   a. Dose 0.1 mL per 5 to 10 kg IM

F. Nonsteroidal antiinflammatory drugs
1. Carprofen 4 mg/kg IM
2. Meloxicam 0.2 mg/kg IM
3. Deracoxib 0.5 to 1.0 mg/kg PO
4. Tepoxalin 10 mg/kg PO
5. Firocoxib 5 mg/kg PO
6. Robenacoxib 1 mg/kg PO

Induction

Preoxygenate compromised and brachycephalic dogs by increasing inspired oxygen concentrations for 3 to 5 minutes via a face mask attached to a circle or nonrebreathing system

I. IV

A. Catheterize vein (generally the cephalic vein)
1. Consider additional catheters if there is the potential for significant blood loss or infusions of ancillary drugs are part of the plan

B. Start IV fluid administration to ensure catheter patency
1. Lower fluid bag or bottle below the dog's thorax to allow blood to siphon back into catheter to confirm catheter placement

C. Inject drug(s) at an appropriate rate(s), allowing time (15 to 30 seconds) for equilibration before administering further increments

TABLE 20-2 Injectable Anesthesia Technique Including Infusion in Dogs

	Premedication	Induction	Maintenance	Comment
1	Hydromorphone-diazepam 0.1 mg/kg-0.2 mg/kg IM	Propofol 4 mg/kg IV + fentanyl 2 µg/kg IV + atropine 40 µg/kg IV	Propofol* 0.2-0.4 mg/kg/min IV + fentanyl 0.1-0.5 µg/kg/min IV	Whining or paddling may occur in recovery
2	—	Propofol 5 mg/kg	Propofol* 0.4 mg/kg/min	Provide a light plane of anesthesia; ventilatory support is recommended
3	Hydromorphone-diazepam 0.1 mg/kg-0.2 mg/kg IM	Propofol 2-4 mg/kg (greyhound)	Propofol* 0.4 mg/kg/min	Muscle tremors may occur

*Alternate "induction": alfaxalone-2-hydroxypropyl-beta-cyclodextrin (HPCD) 2 mg/kg IV followed by 0.07 mg/kg/min.

D. Specific IV induction drugs (see Chapter 8)
   1. Propofol 4 to 10 mg/kg IV (Table 20-2)
   2. Ultrashort-acting barbiturates
      a. Thiopental 2% to 5%; 8 to 20 mg/kg IV
      b. Methohexital 2%; 3 to 8 mg/kg IV
   3. Etomidate 0.5 to 2 mg/kg IV
   4. Ketamine 5 to 10 mg/kg IV
   5. Short-acting barbiturates
      a. Pentobarbital 10 to 30 mg/kg IV
   6. Injectable drug combinations
      a. Diazepam (or midazolam)-lidocaine-thiopental: diazepam 0.2 mg/kg IV, lidocaine 2 mg/kg IV, and thiopental 4 mg/kg IV; do not mix the drugs
         (1) Useful in animals with central nervous system and/or cardiovascular depression
         (2) Stabilizes myocardium
         (3) Lidocaine reduces amount of thiopental required

b. Diazepam (or midazolam)—propofol: diazepam 0.2-0.5 mg/kg IV, propofol 1-3 mg/kg IV to effect
c. Ketamine 5 mg/kg IV. Maximum effect is reached 60 to 180 seconds after drug administration. Midazolam can be used instead of diazepam
   (1) Mix equal parts of diazepam (5 mg/mL in stock vial) and ketamine (100 mg/mL in stock vial) to yield a mixture that is 2.5 mg/mL diazepam and 50 mg/mL ketamine
   (2) Use 1 mL of mixture per 10 kg; add 0.1 mL medetomidine or dexmedetomidine for added analgesia and sedation
d. Ketamine-midazolam-butorphanol/oxymorphone: ketamine (7.5 mg/kg IV) and midazolam (0.375 mg/kg IV) with or without the 10-minute previous administration of butorphanol (0.2 mg/kg IV) or oxymorphone (0.1 mg/kg IV)
   (1) Use with butorphanol or oxymorphone to improve induction
e. Oxymorphone/hydromorphone-diazepam: oxymorphone (0.05 mg/kg IV)/hydromorphone (0.1 mg/kg IV), and diazepam (0.2 mg/kg IV)
   (1) Induction effect is evident within 1 minute
   (2) Additional amounts (same dose) of oxymorphone/hydromorphone (IV) may be necessary for intubation
f. Fentanyl-diazepam for high risk dogs: 0.2-0.5 mg/kg IV diazepam and 5 μg/kg IV fentanyl repeated 2-3 times to effect
   (1) Induction effect is evident within 1 minute
   (2) Additional administrations (same dose) may be necessary for intubation; heart rate may decrease and can be treated with an anticholinergic (ex. Atropine)

II. Inhalant anesthesia

A. Sevoflurane or isoflurane produces optimal control of anesthesia. The odor of sevoflurane is less offensive than isoflurane and induction is faster (lower blood/gas partition coefficient).
   1. Face mask
      a. Be aware of potential for vomiting and possible aspiration

b. Ensure adequate physical restraint
c. Environmental pollution is significant

2. Induction chamber
   a. For very small, aggressive dogs
   b. Use high fresh-gas flow rates (4 to 5 L/min)
   c. Monitor closely for loss of righting reflex, then remove from chamber and complete induction with a mask
   d. Not recommended for routine use because control of anesthetic delivered is poor and atmospheric pollution with anesthetic gases is significant

Orotracheal Intubation

I. Dogs are usually intubated in sternal recumbency

II. Open the dog's mouth and manipulate the tongue to the side with the endotracheal tube; grasp the tongue with a gauze sponge, straighten the head and neck, and extend the tongue between the lower canine teeth to hold the mandible open (Fig. 20-6, *top left*)



FIG. 20-6. Placing an endotracheal tube into the trachea of a dog (orotracheal intubation) is facilitated by extending the head and neck, widely opening the dog's mouth, pulling out the dog's tongue, and visualizing the larynx. The head and neck should be extended.

III. Locate the larynx and insert the endotracheal tube
- A. Direct visualization
- B. Use a laryngoscope to facilitate visualization of the larynx and reflect epiglottis rostral and ventral (see Fig. 20-6, *top right and bottom left*)
- C. Potential difficulties
  1. Laryngospasm (0.1 mL lidocaine sprayed on the laryngeal cartilages reduces spasms)
     a. Larynx sensitized
  2. Dog not adequately anesthetized
  3. Soft-palate displacement prevents rostroventral movement of the epiglottis; push the soft palate dorsally with the endotracheal tube to visualize the epiglottis
  4. Mass involving the larynx or pharynx; may need a smaller tracheal tube or tracheotomy
- D. Turn on oxygen flowmeter
- E. Secure the tube to the dog and connect the breathing system to the endotracheal tube (see Fig. 20-6)
- F. Monitor heart rate, pulse, and respirations
  1. If pulses are present, turn on the vaporizer and nitrous oxide if desired
  2. If pulses are weak, leave oxygen on. Diagnose the cause of the weak pulses and resuscitate; do not start inhalant drugs (see Chapter 29).
  3. Spontaneous ventilation should be 4 to 6 breaths/min minimum (assist ventilation if required)
  4. Apnea or dyspnea
     a. Anesthetic induction drugs may depress ventilatory drive; begin manual ventilation (2 to 4 breaths/min) using the breathing system
     b. Endotracheal tube may be obstructed or kinked (dyspnea)
     c. If bronchial intubation has occurred, withdraw the tube into the trachea
     d. Pneumothorax or pneumomediastinum
        (1) Remove intrathoracic air by percutaneous needle insertion
        (2) Evaluate hemodynamic status
- G. Set the vaporizer to desired maintenance concentration and adjust as necessary
- H. Connect monitors (e.g., electrocardiogram, pulse oximeter, blood pressure)

Maintaining Anesthesia

I. Inhalant anesthetics (isoflurane, sevoflurane) are commonly used to maintain anesthesia for moderate and prolonged procedures (30 minutes to hours; see Chapter 9). Injectable techniques including total intravenous anesthesia (TIVA; see Table 20-2) are useful for shorter procedures (less than 1 hour).
- A. TIVA can be produced by administering propofol (0.25 mg/kg/min) or alphaxalone (0.07 mg/kg/min)
- B. Various analgesic adjuncts can be administered to reduce anesthetic requirements in dogs; opioids and alpha$_2$-agonists are frequently administered as a constant rate infusion
  1. Fentanyl 0.3 to 0.7 μg/kg/min
  2. Dexmedetomidine 0.10 to 0.25 μg/kg/min

II. Monitoring (see Chapter 14): record doses and time of drug administration; readjust doses according to response, depth of anesthesia, and amount of analgesia needed

III. Check patency of airway frequently
- A. Blocked or kinked tube
- B. Tube impinging at bifurcation of trachea
- C. Do not overinflate lungs (P_I = 15 to 20 cm H_2O; V_T = 10 to 15 mL/kg)

IV. Maintain the endotracheal tube, head, and neck in a natural, slightly curved position to prevent kinking of the tube; position the dog to avoid excessive flexion of neck, abduction of limbs, and pressure on thorax

V. Calculate IV fluids needed and adjust fluid flow rate (approximately 5 to 10 mL/kg/hr); record all fluids (the infusion rate, total volumes), electrolytes, and other drugs administered

VI. Complete anesthetic record (Fig. 20-7)
- A. Note the effects of preanesthetic findings and drug effects
- B. Note the start and end of the anesthetic period
- C. Note the start and end of surgery
- D. Note major surgical events (number 1 → x)
- E. Note changes in dog's status, cardiorespiratory variables, and anesthetic technique
- F. Note laboratory results during anesthesia (e.g., pH and blood gases, electrolytes, packed cell volume [PCV], total protein [TP], hemoglobin)

VII. Turn off the vaporizer immediately if cardiopulmonary emergency occurs

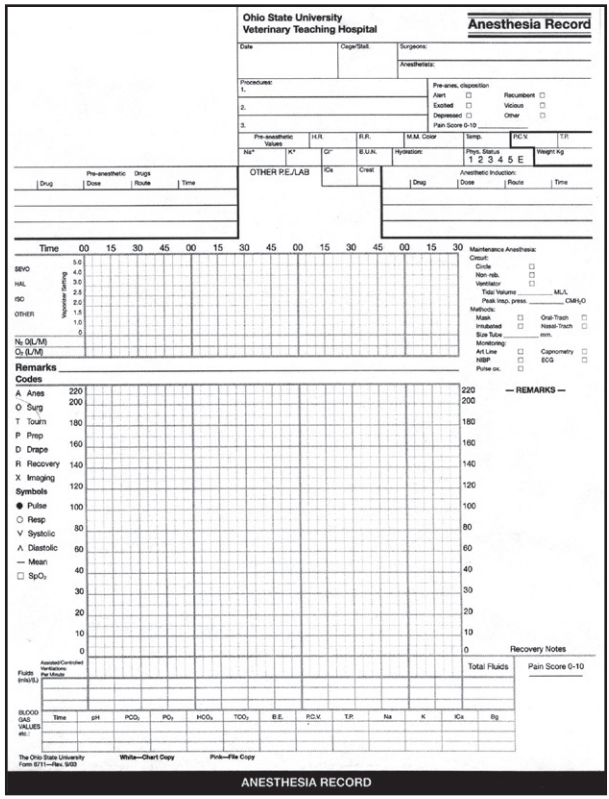


FIG. 20-7. The anesthetic record is a legal document and is used to record all anesthetic and surgically related events.

VIII. Nitrous oxide: turn off N_2O 5 to 10 minutes before the end of anesthesia to hasten recovery and prevent diffusion hypoxia (see Chapter 9)

IX. Turn off the inhalant anesthetic at the end of surgery or earlier, depending on the depth of anesthesia

X. Oxygen: deliver (20 mL/kg or more) during the recovery period; empty the rebreathing bag to dump anesthetic gases and hasten recovery

The Recovery Period

I. Deflate the endotracheal tube cuff; remove it when the animal swallows and/or coughs

II. Pull out the dog's tongue frequently to check its mucous membrane color and administer oxygen if necessary (endotracheal tube, mask, oxygen cage) to maintain oxygenation
III. Position the dog in sternal recumbency with its head extended
IV. Observe the dog until it can maintain sternal recumbency
V. Keep the airway free of secretions (use postural drainage, sponges, and suction tubes)
VI. Check temperature (>36° C); raise and maintain body temperature using towels, heating pads, warm air blankets, or forced air blankets (see Chapter 17)
VII. Change the dog's position frequently and stimulate it by rubbing its body, rolling it from side to side, and flexing and extending its limbs
VIII. Additional tranquilizers (small doses) or analgesics may be needed if the dog becomes excited, delirious, or is in pain during recovery
IX. Maintain IV fluids as needed
    A. Occasionally cardiovascular support may be required (see Chapter 29)
        1. Dopamine 5 to 10 μg/kg/min
        2. Dobutamine 1 to 5 μg/kg/min
X. Consider drug antagonists
    A. Opioids: naloxone
    B. α_2-Agonists: yohimbine, tolazoline, and atipamezole
    C. Benzodiazepines: flumazenil
    D. Respiratory depression: doxapram
    E. Bradycardia: atropine, glycopyrrolate

21 Anesthetic Procedures and Techniques in Cats

"Again I must remind you that a dog's a dog–a cat's a cat."
T. S. ELIOT

OVERVIEW

Cats are not small dogs. Some preanesthetic drugs (acepromazine, butorphanol, diazepam) that work well when administered as single drugs to dogs do not consistently produce a calm, tractable cat that is amenable to physical restraint. Combining drugs from various classes in reduced doses should be considered in cats to increase predictability and reduce unwanted side effects. Combination drug therapy requires a comprehensive knowledge of the pharmacology of anesthetic drugs, their interactions, and potential side effects. Because of their size, cats are prone to hypothermia, so measures should be used to reduce anesthetic duration and provide external warming.

General Considerations

I. A variety of anesthetic procedures and techniques can be used to safely produce sedation, analgesia, and anesthesia in cats. Local anesthetic techniques should be considered to provide additional analgesia.

II. The choice of anesthetic regimen is influenced by the following characteristics:
- A. Age, breed, weight
- B. Temperament
- C. Health and physical condition
- D. The purpose of chemical restraint and anesthesia
- E. Anticipated duration of anesthesia
- F. The familiarity of personnel with the drugs being used
- G. Concurrent medication
- H. Available assistance

III. Drugs that can be antagonized are preferred

IV. Endotracheal intubation should be performed whenever possible to ensure a patent airway

V. Careful and attentive monitoring is mandatory to recognize and compensate for drug-related effects
VI. Food and water should be withheld for about 6 and 2 hours before surgery, respectively, except in very small, very young, or diseased cats

Preanesthetic Evaluation (See Chapter 2)

I. Review history and current drug therapy
II. Perform a physical examination
III. Review available laboratory data
IV. Formulate a specific anesthetic plan (Fig. 21-1)
  A. Determine whether additional preoperative tests are needed
  B. Choose appropriate drugs
V. Intravenous catheter placement is recommended in case of emergency
VI. Gather appropriate equipment and supplies
  A. Endotracheal tube (see Chapter 11)
    1. Select endotracheal tube diameter based on the size of the cat (usual range 2 to 5 mm, inner diameter [ID]; Table 21-1)
    2. If using a cuffed endotracheal tube, check cuff for leaks prior to use by injecting air; deflate prior to placement
    3. Use a rigid or flexible stylet for small-diameter, flimsy tubes
    4. Use an uncuffed tube in very small cats (see Fig. 20-2)
    5. Use a small amount of sterile lubricant
  B. Laryngoscope (see Fig. 20-3)
    1. Aids intubation by allowing visualization, illumination, and manipulation of the tongue and laryngeal structures
  C. Anesthetic machine and breathing system
    1. Size and type of anesthetic system (rebreathing; nonrebreathing; see Chapter 12) determined by body weight

TABLE 21-1 Endotracheal Tube Size for Cats

Body Weight (kg)	Tube Size, mm (Inner Diameter [ID])
1	3
2	4
5	5

PREANESTHETIC EVALUATION

ANESTHETIST:_____
DATE:_____
CLINICIAN:_____
WARD/CAGE OR STALL #:_____

PROCEDURE: .....

BODY WEIGHT: ..... **AGE:** .....

TEMPERAMENT:

OBJECTIVE FINDINGS
Temp_____ Pulse_____ Resp._____
Cardiac auscultation_____
Pulse quality _____
Mucous membrane color_____
Capillary refill time_____
Respiratory auscultation _____
_____
ASSESSMENT: Physical status I II III IV V E
Reasons:

CBC
WBC_____ TP_____ PCV_____
Fibrinogen _____
SERUM CHEMISTRIES
BUN_____ GLUCOSE_____
AST(SGOT)_____
ALT(SGPT)_____
URINE SPECIFIC GRAVITY_____
OTHER RESULTS _____
PRIOR ANESTHESIA _____

COMPLICATIONS ANTICIPATED pre op, intra op, post op: consider age , body wt., breed, position, surgical procedure, physical status.

Plan Anesthesia regimen (include reasons as related to this animal)
(Include premeds, induction agent, inhalation agent, O_2 flow rate, post op analgesics)

DRUG	ROUTE	DOSE/#	MG	ML	REASONS OR JUSTIFICATION

MONITORING: Esophageal stethoscope, Doppler, ECG, Temp. Probe, Blood gas, Arterial Line, Other_____

IV FLUID TYPE_____ Dose: MLS/HR_____ DROPS/MIN_____

ADMINISTRATION SET: MINI DRIP (60 drops/ml) MAXI DRIP (10 drops/ml)

Approved_____

FIG. 21-1. A preanesthetic evaluation and anesthetic plan should be individually developed for each animal.

a. Use a small-animal anesthetic machine (adult human anesthetic system)
   (1) Use a pediatric circle system for cats weighing more than 3 kg
   (2) Use the nonrebreathing system for cats weighing less than 3 kg

2. The size of the rebreathing bag should be at least 3 to 5 times the tidal volume (V_T). The V_T is usually between 10

and 15 mL/kg of body weight (e.g., 5 kg × 10 mL/kg = 50 mL V_T).

3. Refill carbon dioxide absorbent canister if material is exhausted (discolored or dry)
4. Evaluate anesthetic system for possible malfunctions (see Chapter 12)
   a. Fill vaporizer and check operation
   b. Turn on flowmeters and check for free movement of indicator balls or slides
   c. Connect the nonrebreathing system or circle system to anesthetic machine and check for leaks or close the pop-off valve and pressurize (increase the oxygen flow) the system to 20 to 30 cm water and maintain for 15 seconds; check for leaks
5. Connect waste gas scavenging system to the nonrebreathing system or the circle breathing circuit

D. Fresh gases
   1. Oxygen
      a. Connect to "house" oxygen system, if present
      b. Attach smaller (E) tanks to machine; change oxygen tank if pressure gauge falls below 500 pounds per square inch (psi)
   2. Nitrous oxide (used to produce analgesia)
      a. Optional
      b. Change tank if pressure gauge falls below 750 psi
E. Intravenous (IV) administration equipment
   1. IV catheters (18- to 23-gauge)
   2. Appropriate volume of IV fluids
      a. Balanced electrolyte solutions (e.g., lactated Ringer's solution, Plasmalyte)
      b. Use 250 mL bags or smaller to prevent fluid overload
      c. Administer 5 to 10 mL/kg/hr
   3. Solution administration set (mini-drip; 60 drops/mL)
   4. Fluid infusion pump (see Fig. 20-5)
F. Drugs
   1. Calculate appropriate drug dose and volume
   2. Draw drugs into labeled syringes
G. Monitoring equipment (see Chapter 14)
   1. Electrocardiographic monitor
   2. Indirect blood pressure (Doppler with sphygmomanometer, oscillometric)
   3. Pulse oximeter

4. Thermometer
5. Esophageal stethoscope
6. End-tidal gases (oxygen, carbon dioxide, inhalant)

H. Ancillary supplies
1. Gauze sponges (4 by 4 inch)
2. Adhesive tape
3. Roll gauze to secure endotracheal tube
4. Forced hot air blanket

Preanesthetic Medication (See Chapter 3)

I. Choice of drugs determined by the cat's preoperative condition and the surgical procedure to be performed

II. Intramuscular (IM) or subcutaneous (SQ) drugs should be administered 10 to 20 minutes before catheterization and induction of anesthesia

III. Drugs used before anesthesia

A. Anticholinergics
1. Atropine 20 to 40 μg/kg IM, IV, or SQ
2. Glycopyrrolate 5 to 10 μg/kg IM, IV, SQ
3. Not routinely required, can be used to decrease salivation
4. Usually administered during anesthesia in response to bradycardia

B. Tranquilizers
1. Acepromazine 0.025 to 0.2 mg/kg IM
2. Diazepam or midazolam 0.1 to 0.2 mg/kg IV
   a. Benzodiazepines (administered alone) can produce restlessness, apprehension, and disorientation in cats, making them more difficult to restrain
3. Single-drug use is recommended only for old or depressed cats

C. Opioids (give in combination with tranquilizers)
1. Butorphanol 0.2 to 0.4 mg/kg IM
2. Buprenorphine 0.005 to 0.02 mg/kg IM
3. Hydromorphone 0.05 mg/kg IM
4. Oxymorphone 0.1 to 0.3 mg/kg IM
5. Morphine 0.1 to 0.2 mg/kg IM
6. Fentanyl patch 12.5-25 μg/kg/hr

D. α_2-Agonists
1. Dexmedetomidine 5 to 40 μg/kg IM or IV
2. Medetomidine 10 to 80 μg/kg IM or IV
3. Xylazine 0.2 to 1.0 mg/kg IM or IV
4. Romifidine 0.09 to 0.18 mg/kg IM or IV

E. Ketamine 5 to 10 mg/kg IM (give in combination with tranquilizer or an α_2-agonist)
F. Tiletamine-zolazepam-Telazol 2 to 10 mg/kg IM or IV
G. Popular preanesthetic drug combination in cats
   1. Dexmedetomidine (6 to 40 μg/kg) with ketamine (5 mg/ kg) and butorphanol (0.2 mg/kg)
   2. Acepromazine (0.2 mg/kg) with hydromorphone (0.05 to 0.10 mg/kg)
      a. Mix and give IM or SQ
   3. Midazolam (0.2 mg/kg) with hydromorphone (0.05 to 0.10 mg/kg)
      a. Mix and give IM or SQ
H. Nonsteroidal antiinflammatory drugs
   1. Must be used with caution in cats because of gastrointestinal and renal effects
   2. Meloxicam 0.3 mg/kg SQ, one time
   3. Carprofen 2 mg/kg SQ, one time
   4. Robenacoxib 1 mg/kg orally (PO), once daily x 6 days total (cats)

Induction

I. Intravenous
A. Catheterize vein(s) (generally the cephalic or medial saphenous vein)
B. Start IV fluid administration to ensure catheter patency
   1. Lower fluid bag or bottle below cat's thorax to allow blood to siphon back into catheter; this confirms catheter placement within the vein
C. Inject induction drug(s) slowly (15 to 30 seconds); allow time for equilibration before administering further increments
D. Specific IV induction drugs (see Chapter 8)
   1. Ketamine 2 to 6 mg/kg IV
   2. Propofol 3 to 10 mg/kg IV (Table 21-2)
   3. Ultrashort-acting barbiturates
      a. Thiopental 2% to 5%; 6 to 14 mg/kg IV
      b. Methohexital 2%; 3 to 8 mg/kg IV
   4. Etomidate 0.5 to 2.0 mg/kg IV
   5. Short-acting barbiturates
      a. Pentobarbital 25 mg/kg IV
   6. Popular injectable drug combinations
      a. Diazepam-ketamine: diazepam 0.2 mg/kg IV and ketamine 5 mg/kg IV

TABLE 21-2 Injectable Anesthesia Technique Including Infusion in Cats

	Induction	Maintenance	Comment
1	"Kitty Magic": Dexmedetomidine Butorphanol Ketamine	 10-30 ug/kg IM 0.2-0.6 mg/kg IM 2-8 mg/kg IM	 Mixed in one syringe; Produces profound sedation to anesthesia for up to 1 hr Reverse with Atipamezole: 100-300 ug/kg
2	Propofol 3-6 mg/kg	Propofol* 0.22 mg/kg/min CRI or Propofo* 0.14 mg/kg/min CRI + ketamine 23 μg/kg/min CRI (loading dose 2 mg/kg)	Stable hemodynamics
3	Propofol 3-6 mg/kg	Propofol* 0.05-0.10 mg/kg/min CRI or Propofol* 0.025 mg/kg/min CRI + ketamine 23 or 46 μg/kg/min	

*Alternatively: alfaxalone-2-hydroxypropyl-beta-cyclodextrin (HPCD) 2 mg/kg IV followed by 0.07-0.1 mg/kg/min.

(1) Mix equal parts of diazepam (5 mg/mL in stock vial) and ketamine (100 mg/mL in stock vial) to yield a mixture that is 2.5 mg/mL diazepam and 50 mg/mL ketamine
(2) Add an additional 0.1 mL of medetomidine (10 μg/kg) or dexmedetomidine (5 μg/kg) if the cat is healthy and fractious
(3) 0.1 mL/kg of mixture IV
(4) Midazolam can be substituted for diazepam

b. Tiletamine (50 mg/mL), zolazepam (50 mg/mL), ketamine (80 mg/mL), and xylazine (20 mg/mL)
(1) Mix and give 0.2 to 0.3 mL/cat IM
(2) Cats can be spayed or neutered with single injection

c. Fentanyl, 2-3 μg/kg IV, can be administered 1-2 minutes before induction to anesthesia to provide added

analgesia and reduce the dose of injectable IV drug in high anesthetic risk cats

NOTE: Drug combination for feral cats:
TKM (or TKD)
Add 4 mL of 100 mg/mL ketamine and 1 mL of 1 mg/mL medetomidine (or 1 mL of 0.5 mg/mL dexmedetomidine) to a 5 mL bottle of Telazol
Dose: 0.1 to 0.2 mL/5 to 10 kg IM

II. Inhalant anesthetic induction
- A. Sevoflurane or isoflurane can be used for mask or chamber induction in cats. Sevoflurane's odor is less offensive than isoflurane and induction is faster (lower blood/gas partition coefficient)
  1. Face mask (Fig. 21-2)
     a. Be aware of the potential for vomiting and possible aspiration
     b. Provide adequate physical restraint
  2. Induction chamber (Fig. 21-3)
     a. Use high, fresh-gas flow rates (4 to 5 L/min)
     b. Monitor cat closely for loss of righting reflex, then remove from chamber and complete induction with a mask
     c. Not recommended for routine induction because atmospheric pollution with anesthetic gases is very significant



FIG. 21-2. A face mask can be used to induce anesthesia in compliant or adequately sedated cats or small dogs.

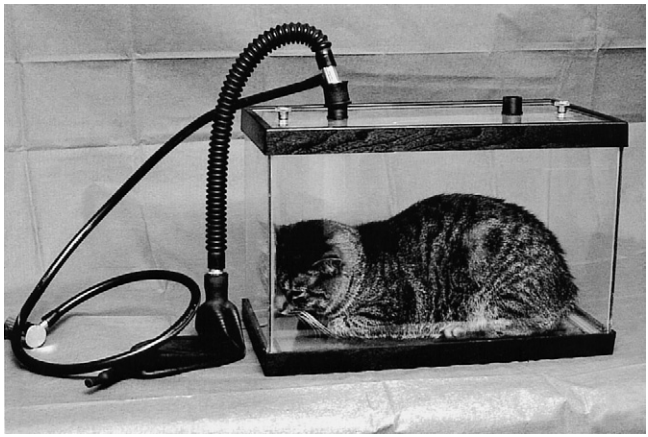


FIG. 21-3. An induction chamber is used to induce inhalant anesthesia in fractious or aggressive cats.



FIG.21-4. A flexible stylet is frequently used to stiffen the endotracheal tube and facilitate placement of an endotracheal tube in the trachea of cats.

Orotracheal Intubation

I. Open the cat's mouth and manipulate the tongue to the side with the endotracheal tube; grasp the tongue with a gauze sponge, straighten the head and neck, and extend the tongue between the lower canine teeth to hold the mandible open
II. Locate the larynx and insert the endotracheal tube (see Chapter 11; Fig. 21-4)

A. Direct visualization
B. Use a laryngoscope to facilitate visualization of the larynx and reflect the epiglottis rostral and ventral
C. Potential difficulties
   1. Laryngospasm (0.1 mL 2% lidocaine sprayed onto the laryngeal cartilages reduces spasms)

NOTE: Do NOT! use Cetacaine (causes methemoglobinemia).

      a. Cat may not be adequately anesthetized
      b. Larynx may be sensitized
   2. Small tubes may be too pliant to easily place. Use a stylet to stiffen them.
   3. Soft-palate displacement may prevent rostroventral movement of the epiglottis; push the soft palate dorsally with the endotracheal tube to release epiglottis
   4. Mass involving the pharynx and larynx; may need a smaller tracheal tube or tracheotomy
   5. Vomiting or regurgitation
      a. Place the cat in a "head down" position
      b. Apply suction to the pharynx and trachea if required
      c. Rapidly intubate and inflate the cuff to minimize further aspiration (if any)
D. Turn on oxygen (be careful not to overinflate lungs)
E. Connect the breathing system (Y-piece or elbow) to the endotracheal tube, and secure the tube to the cat using roll gauze or discarded solution-administration tubing
F. Monitor heart rate, pulse, and respirations
   1. Normal heart rate and pulse: turn on the vaporizer and nitrous oxide (if desired)
   2. Low heart rate or weak pulse: leave oxygen on, diagnose the cause of the weak pulses, and resuscitate; do not start inhalant drugs (see Chapter 29)
   3. Spontaneous ventilation: minimum of 4 to 6 breaths/min (assist ventilation if required)
   4. Apnea or dyspnea
      a. Anesthetic induction drugs may have depressed the cat's ventilatory drive; begin manual ventilation (2 to 4 breaths/min) using the breathing system

NOTE Be careful not to overinflate lungs: P_I = 15 to 20 cm H_2O; V_T = 10 to 15 mL/kg); lung overinflation can cause pneumomediastinum, pneumothorax.

b. Endotracheal tube may be obstructed or kinked
c. If bronchial intubation has occurred, withdraw the tube into the trachea

G. Set the vaporizer to a maintenance concentration determined by monitoring responses
H. Connect monitors (e.g., Doppler, electrocardiogram, pulse oximeter, temperature)

LOCAL ANESTHETIC TECHNIQUES (SEE CHAPTER 7)

I. Declaw procedure
A. Use 0.2% ropivacaine or 0.25% bupivacaine (total dose 1 mg/kg)
B. Perform a ring block just proximal to the level of the carpus (see Fig. 7-3)

II. Epidural anesthesia

Maintaining Anesthesia (See Chapter 20)

I. Various analgesic adjuncts can be administered to reduce anesthetic requirements in cats; opioids and α_2-agonists are frequently administered as a constant rate infusion
A. Fentanyl 0.1 to 0.5 μg/kg/min
B. Dexmedetomidine 0.10 to 0.25 μg/kg/min

II. Monitor body temperature (see Chapter 11)
A. Prevent and treat hypothermia (warm air heating devices)
B. Treat hyperthermia (opioid antagonists, external cooling)

Recovery (See Chapter 20)

I. Check respirations, pulse, and temperature (>36° C) at frequent intervals until in sternal recumbency

Anesthetic Procedures and Techniques in Horses

22

"The little neglect may breed mischief … for want of a nail the shoe was lost; for want of a shoe the horse was lost; and for want of a horse the rider was lost."
BENJAMIN FRANKLIN

OVERVIEW

Horses may be the most difficult domestic species to safely anesthetize. Mortality rates for horses are significantly higher than for cats and dogs, ranging from 1% to 2% in horses compared with about 0.1% in dogs and cats. Individual equine temperament varies considerably and has significant influence on the dose of drug required and selection of the anesthetic technique. The ability to anticipate drug effects and drug actions in horses is the single most important aspect of safe and effective equine anesthesia. Appropriate preanesthetic medications in conjunction with boluses and infusions (total intravenous [IV] anesthesia) of anesthetic drugs are combined with physical restraint to induce general anesthesia in horses. Anesthetic techniques are designed to produce rapid and safe induction to and recovery from recumbency and to maximize muscle relaxation and analgesia while maintaining optimal cardiopulmonary status. Horses frequently benefit from assistance in regaining and maintaining a standing position after general anesthesia.

General Considerations

I. Preparing the horse for surgery
- A. Withhold food for approximately 4 to 8 hours before surgery except in foals
  - 1. Do not withhold water
- B. Perform a complete physical examination with emphasis on cardiorespiratory function
- C. Determine body weight using a scale or a girth weight estimator tape
  - 1. Note body type (e.g., lean/racing, conditioned, draft)
- D. Groom the horse and wipe with a moist cloth to remove dander and debris
- E. Clean the feet before induction; pull or pad shoes to prevent injury

F. Prepare (clip and scrub) the surgical site before induction (if possible) to reduce anesthesia time
   1. Sedation may be required to complete surgical preparation
G. Place and secure an IV catheter in a jugular vein before induction (Fig. 22-1 *A*, and *B*)
H. Administer preanesthetic medications (antibiotics, analgesic drugs) 5 to 30 minutes before induction
I. Rinse the mouth thoroughly with water before induction

II. Proper positioning and appropriate padding of the head, shoulder, and hip minimize the incidence of neuropathies and myopathies

III. All spontaneously breathing horses develop an acid-base disturbance under anesthesia, particularly respiratory acidosis (increased $PaCO_2$) or hypoxemia ($PaO_2 < 60$ mm Hg) when breathing air

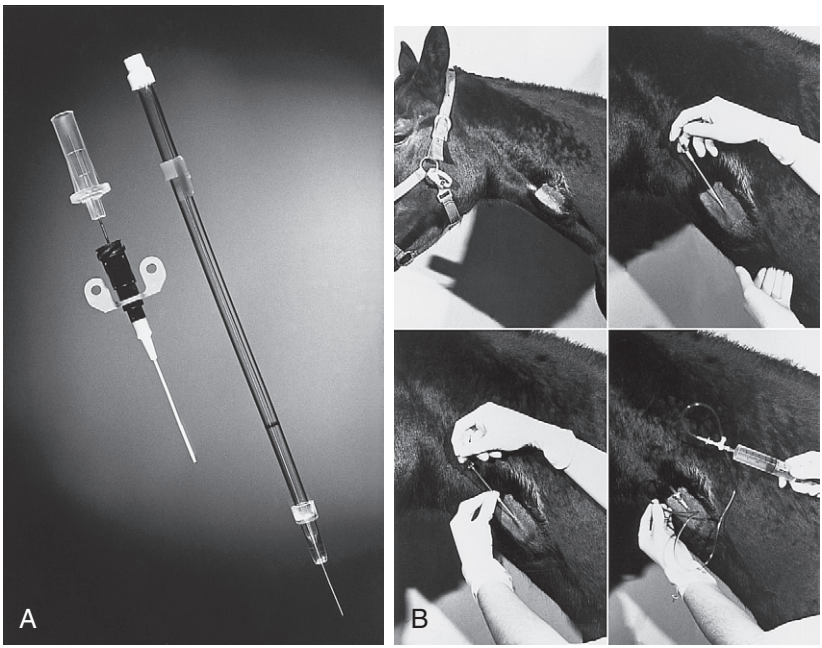


FIG. 22-1. A, Types of intravenous (IV) catheters: over-the-needle (left) and through-the-needle (right). **B,** Placement of an IV catheter in the horse. Do not attempt to withdraw an over-the-needle catheter back onto the needle once it has been advanced. This could lead to catheter shearing and loss of the catheter tip into the horse's blood stream.

IV. Controlled positive pressure ventilation can be used to maintain normal $PaCO_2$ and may help to maintain arterial blood oxygenation (PaO_2)
V. Prevent hypotension and hypoxemia to help avoid perioperative complications, including myopathy
VI. Horses should be closely monitored during the recovery period and, if needed, assisted to a standing position
   A. Nasotracheal intubation may be required in horses that snore or demonstrate signs of upper airway obstruction
   B. Alternatively, phenylephrine can be sprayed into each nostril to decrease nasal congestion, but this therapeutic technique is frequently ineffective

Preanesthetic Evaluation

I. Review history
II. Conduct a physical examination
   A. Determine age, weight, sex, body type, physical condition
   B. Temperament of the horse and concurrent disease (see Chapter 2)
   C. Emphasize evaluation of the cardiopulmonary system; check for subclinical respiratory disease
      1. Place a large plastic bag over the nostrils and allow the horse to rebreathe exhaled air while auscultating the horse's lung sounds
   D. Determine the degree of lameness or ataxia if present
      1. Severely lame horses should be sedated at the site of induction to anesthesia to avoid accidents
      2. Some horses may require assistance after sedation
   E. Review the current and previous drug history
   F. Consider the consequences (e.g., tissue trauma, pain, blood loss, duration) of the surgical procedure to be performed
   G. Prepare an anesthetic care plan
III. Conduct a laboratory evaluation
   A. Routine evaluation
      1. Complete blood count (packed cell volume, white blood cell count)
      2. Total protein (hydration status)
   B. Suggested further evaluation
      1. Serum electrolytes
      2. Serum chemistries (lactate, muscle enzymes)
      3. Acid-base balance (pH, PaO_2, $PaCO_2$)

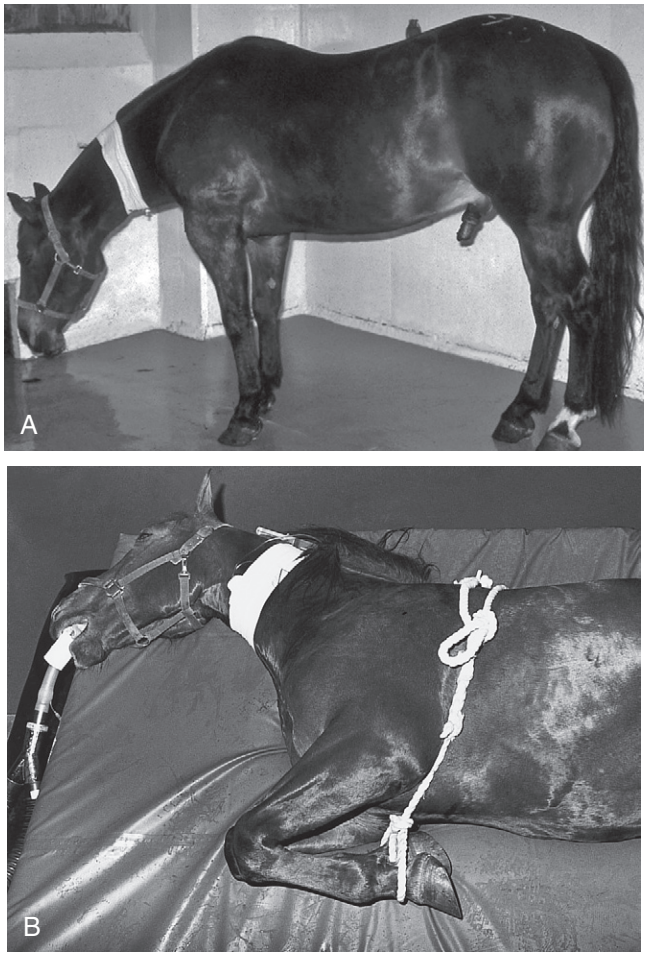


FIG. 22-2. Horses should be adequately sedated before anesthesia (A) and are usually positioned on large foam-rubber pads or on air or water mattresses with their front legs restrained (B). Once the horse is recumbent, the halter should be removed to prevent facial nerve trauma.

Preanesthetic Medications (Fig. 22-2, *A*)

I. Xylazine (used to produce sedation, analgesia, and muscle relaxation)

A. Dose: 0.4 to 1.0 mg/kg of body weight IV, 1 to 2 mg/kg intramuscularly (IM)

B. Onset of action: within 2 to 3 minutes after IV administration and within 10 to 15 minutes after IM administration

C. Duration: 30 minutes after IV administration and 60 minutes after IM administration
D. Sinus bradycardia and first- and second-degree atrioventricular block may occur
E. Head-down posture with significant ataxia and muscle relaxation
   1. Some horses develop variable degrees of upper airway obstruction (they snore)
F. Horses are arousable and may overreact to sudden movement or sounds (startle response)
   1. Occasional disinhibition (excitement, aggression) has occurred

II. Detomidine (similar to xylazine)
A. Dose: 10 to 20 μg/kg IV; 20 to 40 μg/kg IM; 60 μg/kg buccally
B. Approximately two times longer duration of action than xylazine
C. Smaller volume of drug required (compared to xylazine or romifidine)
D. Onset of effect about 30 to 45 minutes after sublingual administration
E. Head-down posture with significant ataxia and muscle relaxation
F. Horses are arousable, and occasional disinhibition (aggression) is reported

III. Dexmedetomidine (similar to xylazine)
A. Dose: 3 to 15 μg/kg IV
B. Short duration of effect and can be administered by infusion to sustain effect
C. Significant ataxia may occur

IV. Romifidine (similar to xylazine)
A. Dose: 90 to 120 μg/kg IV; 80 to 120 μg/kg IM
B. Reduced ataxia and head drop compared with xylazine and a longer duration of effect

V. Acepromazine (used to produce a calming effect)
A. Dose: 20 to 80 μg/kg IM; 10 to 40 μg/kg IV
B. Onset of action: within 10 to 20 minutes after IV administration
C. Duration: 2 to 4 hours
D. Decreases in arterial blood pressure may last for 12 hours
E. Potential for persistent penile paralysis

F. Mild to moderate ataxia, no analgesia but may potentiate the analgesic effects of analgesic drugs (opioids, α_2-agonists)

VI. Chloral hydrate (infrequently used to produce or enhance sedation); 20 to 80 mg/kg IV (see Chapter 8)

Anesthetic Equipment

I. Suggested equipment for producing anesthesia in horses:

A. Commercially available 10-, 12-, and 14-gauge, 13-cm catheters are placed in the jugular vein for IV anesthetic drug and fluid administration (see Fig. 22-1, *A*)

B. Orotracheal tubes

1. May not be required for short duration (5 to 15 minutes) anesthesia
2. Choose the largest orotracheal tube possible (30, 26, 20, or 15 mm); tube size designations are related to internal diameter
3. Check the orotracheal tube cuff for leaks
4. Use sterile lubricating jelly
5. Use 25- to 60-mL syringe to inflate the orotracheal tube cuff
   a. Be sure not to overinflate the orotracheal tube cuff to minimize tracheal trauma or collapse (occlusion) of the orotracheal tube
6. Use a 10-cm length of 5-cm diameter polyvinylchloride plumber's pipe as a speculum

C. Pressure bag for administration of IV fluids or drugs (e.g., guaifenesin)

D. Cotton ropes for restraint (Fig. 22-2, *B*)

E. Appropriate padding (see Fig. 22-2, *B*)

F. Monitoring equipment (see Chapters 14 and 15)

1. Electrocardiographic monitor
2. Blood pressure monitoring device (invasive monitoring is preferred)
3. End expired gas monitor (% O_2; end-tidal CO_2; inhalant anesthesia concentration)
4. pH and blood gases (PO_2; PCO_2)

G. Infusion pump for controlled infusion (e.g., lidocaine; dobutamine)

II. Inhalant Anesthetic Equipment

A. Examine the anesthetic machine to ensure the vaporizer is full; test the circle system

1. Larger quantities of inhalant anesthetic are used in large animals because of higher fresh gas flow rates. Vaporizers may need to be refilled during longer procedures.
2. The anesthetic circuit can be checked for leaks by occluding the Y piece, closing the pop-off valve, and flushing the anesthetic circuit with oxygen (O_2)
3. The anesthetic circuit should be capable of maintaining a pressure of approximately 30 cm of H_2O

B. Check O_2 pressure
1. Oxygen tank pressure should be 500 pounds per square inch (psi) or greater
2. Multiple large (H) tanks are required if an O_2-driven ventilator is used

C. Fresh carbon dioxide absorbent should be placed in the canister after every 6 hours of use
D. Fresh gas flow rate
1. Oxygen: 5 to 10 mL/kg; high flow rates (up to 20 mL/kg) are used during induction to rapidly increase inhalant concentrations and denitrogenate

E. Check scavenging (waste gas removal) system
F. Appropriate protective head gear and leg boots; floor mats and pads (inflatable mattress, foam padding)

Induction

I. Ketamine
A. Appropriate sedation and muscle relaxation is required before ketamine is administered
B. Dose: 1.5 to 2.0 mg/kg IV after detomidine, dexmedetomidine, guaifenesin, romifidine, or xylazine (see Chapter 3)
C. Ketamine should be administered with diazepam or midazolam (0.05 to 0.1 mg/kg IV), after an α_2-agonist
D. Short-acting (10 to 15 minutes)
E. May cause apneustic breathing (breath holding) pattern

II. Guaifenesin: centrally acting skeletal muscle relaxant
A. Horses should be adequately sedated before initiating guaifenesin infusion
B. Dose: 50 to 100 mg/kg to produce recumbency; 50 mg/kg to produce ataxia and relaxation
C. 5% to 10% solution (50 to 100 mg/mL); concentrations greater than 15% may cause hemolysis and hives
D. Can be administered before or by infusion with thiopental or ketamine

E. Duration: 15 to 25 minutes
F. Toxic signs include:
1. Apneustic breathing pattern (inspiratory hold) or apnea
2. Muscle rigidity
3. Hypotension

III. Diazepam (muscle relaxant)
A. Enhances muscle relaxation
B. Dose: 0.04 to 0.1 mg/kg IV
C. Administered after sedation and before thiopental or in conjunction with ketamine
D. Duration of effect: 5 to 15 minutes
E. Anti-seizure effects; no analgesia, minimal sedation

IV. Midazolam (similar to diazepam)
A. Dose: 0.04 to 0.1 mg/kg IV
B. Water soluble, not absorbed into plastic

V. Thiopental or propofol
A. Short-acting hypnotics (5-10 minutes)
B. Dose: 2-5 mg/kg IV; combined with guaifenesin (5 mg/mL in 5% guaifenesin), given IV to effect to calm, sedate horses
C. Causes cardiorespiratory depression and may cause transient apnea (dose-dependent)

VI. Telazol (tiletamine/zolazepam)
A. Similar to ketamine-diazepam
B. Dose: 0.5 to 1.5 mg/kg IV
C. Greater muscle relaxation
D. Longer duration of action
E. Greater respiratory depression
F. Longer and poorer recovery than ketamine-diazepam

VII. Isoflurane, sevoflurane: 3% to 7% concentration and high O_2 flow rate can be used for induction in foals after placing a nasotracheal tube or mask
A. Anesthetic risk is reduced if foals are sedated prior to inhalant induction
B. Metabolic pathways are mature in 3-month-old foals

Orotracheal Intubation

I. Two endotracheal tubes (anticipated size and one size smaller) and a speculum or mouth gag should be available for intubation

II. Intubation is performed blindly (Fig. 22-3)
A. Place a speculum (bite block) between the incisors
B. Extend the head and neck
C. Advance the tube over the base of the tongue into the pharynx

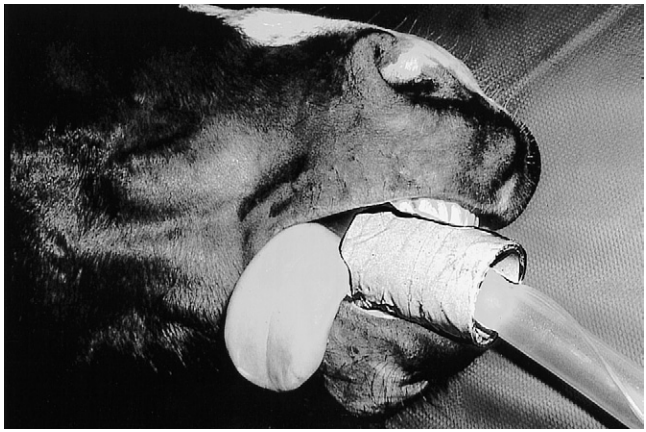


FIG. 22-3. Orotracheal intubation is performed blindly in horses and foals. A speculum or PVC bite block facilitates the process.

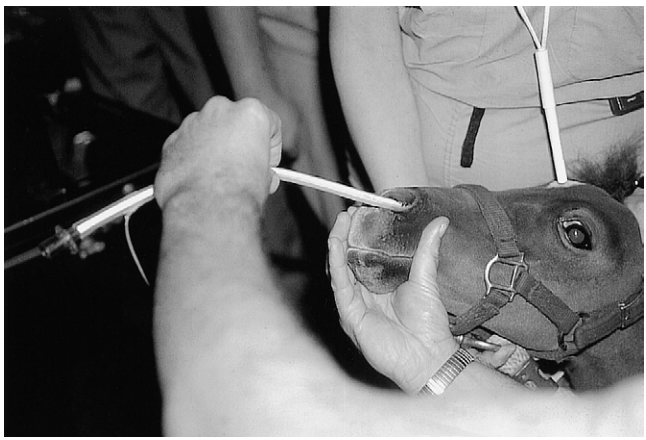


FIG. 22-4. Nasal intubation is easily performed in adult horses and foals.

D. Rotate the tube while advancing it into the trachea
E. Repeat if unsuccessful

III. Make sure that the tube is in trachea, not the esophagus; look for water vapor on tube during exhalation and feel for air movement with breathing

IV. Do not advance the endotracheal tube tip past the thoracic inlet

V. Nasal intubation can be performed in adult horses and foals (Fig. 22-4)

A. Lubricate the tube and insert into the ventral meatus of the nostril

B. Select a tube one to two sizes smaller than the size used for orotracheal intubation

VI. Connect the endotracheal tube to the anesthetic circuit Y-piece
A. The rebreathing bag size should be at least five times the tidal volume; 15-L to 30-L bags are standard

VII. Inflate the orotracheal tube cuff, and check to see that it does not leak by squeezing the rebreathing bag, expanding the animal's lungs
A. Do not overinflate the orotracheal tube cuff; generally, 50 to 75 mL is adequate to inflate the cuff of an endotracheal tube in a 500 kg horse (Fig. 22-5)

Maintaining Anesthesia

I. Avoid over extending the limbs or head and neck
A. Pull the dependent forelimb toward the horse's head to minimize pressure on the triceps muscles to prevent neuropathy and myopathy (lateral recumbency)
B. Remove the halter to prevent facial paralysis

II. Total intravenous anesthesia (TIVA): a mixture of 500 mL of 5% guaifenesin and 500 mg of ketamine with or without 250 to

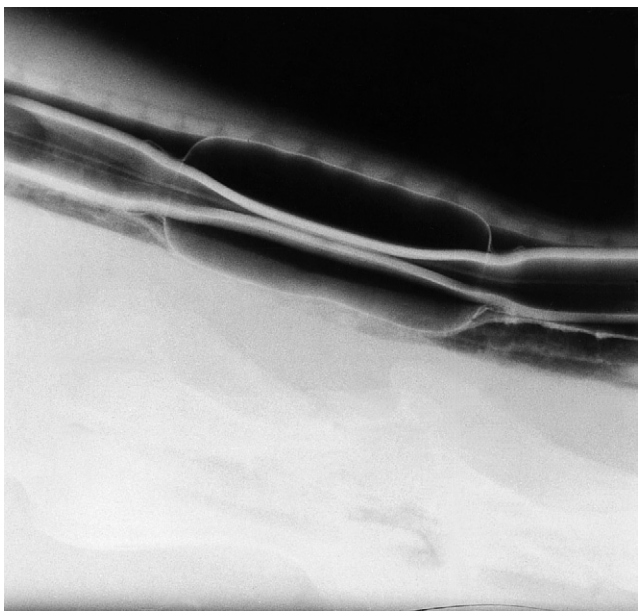


FIG. 22-5. Overinflation of the endotracheal tube cuff can result in endotracheal tube occlusion.

TABLE 22-1 Total Intravenous Anesthesia Technique in Horses

Drug Concentration	Combinations (mg/mL)	Infusion dose
Xylazine	1	1-2 mL/kg/hr to effect
Guaifenesin	50	
Ketamine*	2	
Detomidine	0.02	1-2 mL/kg/hr to effect
Guaifenesin	50	
Ketamine*	2	
Dexmedetomidine	0.001	1-2 mL/kg/hr to effect
Guaifenesin	100	
Ketamine*	2	
Xylazine	1.0	0.5-1 mL/kg/hr to effect
Midazolam	0.1	
Ketamine*	4	

Butorphanol (20 μg/kg) may be added to enhance analgesia.
Ketamine is generally infused at rates of 50 to 150 μg/kg/min after adequate muscle relaxation.
*4 mg/mL ketamine reduces infusion to 0.8 mL/kg/hr.
Propofol infusion (0.2-0.4 mg/kg bwt/min) can be administered to supplement anesthesia

500 mg of xylazine can be mixed together and delivered to effect (Table 22-1)

A. TIVA should be limited to 1 hour
   1. Oxygen should be supplemented
   2. Longer periods of anesthesia may result in prolonged recovery times
B. Midazolam can be used to replace guafenesin IV infusion of midazolam (0.002 mg/kg/min), ketamine (0.03 mg/kg/min), and xylazine (0.016 mg/kg/min); see Table 22-1
C. Propofol infusion (0.2-0.4 mg/kg min) can be administered to supplement anesthesia

III. Inhalant anesthesia
A. Isoflurane: 1% to 3%
B. Sevoflurane: 2% to 5%
C. Ventilation usually needs to be assisted or controlled

IV. Analgesia
A. Morphine 0.04 to 0.10 mg/kg IM
B. Butorphanol 0.01 to 0.04 mg/kg IV or IM
C. Alpha-2 agonists (2 to 3 μg/kg IV detomidine)

V. Monitoring (see Chapters 14 and 15)
- A. Body temperature
  1. Changes very little but usually decreases in adult horses
  2. Decreases in foals
  3. May increase if muscle relaxation is inadequate
- B. Record all anesthetic and surgical events and the animal's response
- C. Monitor all vital signs (i.e., cardiovascular, respiratory) and the depth of anesthesia (i.e., unconsciousness, eye signs)
  1. Lateral nystagmus, tearing, and unstimulated closure of the eyelids occur during light planes of anesthesia
  2. The eye rotates forward, and nystagmus, tearing, and unstimulated closure are reduced at surgical planes of anesthesia
  3. The corneal reflex (closure of the eyelids when the cornea is touched) should always be present
- D. Measure, maintain, and record arterial blood pressure; mean arterial blood pressure should be maintained at values greater than 60 mm of Hg. Treat hypotension.
  1. Administer fluids
  2. Reduce anesthetic level if possible
  3. Administer dobutamine (1 to 3 μg/kg/min) or a bolus of ephedrine (0.05 to 0.10 mg/kg IV)

VI. Administration of fluids (see Chapter 16)

VII. Intravenous anesthetic adjuncts
- A. Detomidine infusion: 0.01 to 0.03 μg/kg/hr IV
- B. Lidocaine infusion: 40 to 60 μg/kg/min after a 2 mg/kg loading dose
  1. Administer a 2 mg/kg loading dose slowly
  2. Reduces inhalant requirement by 20% to 40%
  3. Discontinue 30 minutes before recovery to minimize ataxia
- C. Ketamine infusion: 0.5 to 1.0 mg/kg/hr
  1. Loading dose is not required if ketamine is used for induction
  2. Reduces inhalant requirement up to 50%
- D. Guaifenesin recipes (GKX; see Table 22-1)
  1. Given to effect with reduction of inhalant concentration

Recovery

I. Turn off the inhalant before discontinuing O_2

II. Administer O_2 until the horse is swallowing, if possible; then extubate



FIG. 22-6. An oxygen (O_2) demand or delivery device can deliver high flows (50 L/sec) of O_2 into a face mask or an endotracheal tube.

III. Oxygen is routinely administered:
- A. O_2 humidifier (minimum effective flow rate 15 L/min)
- B. O_2 demand valve (Fig. 22-6)

IV. Sedatives, ropes, slings, and emergency drugs
- A. Make sure the cuff on the endotracheal tube is deflated
- B. Keep the animal's head and muzzle tipped down to allow drainage
- C. Assist the animal to a standing position, if necessary
- D. Administer sedative (50 to 100 mg xylazine IV or 2 to 3 mg detomidine IV) to adult horses when any of these occur:
  1. Excessive nystagmus or oculogyric activity
  2. Excessive muscle tremors
  3. Uncoordinated limb movements; paddling, delirium
  4. Premature attempts to stand but unable to attain a standing position

Potential Anesthetic Problems

I. Hypotension (mean arterial blood pressure less than 60 mm Hg)

II. Hypoventilation ($PaCO_2$ greater than 55 mm Hg)

III. Hypoxemia (PaO_2 less than 60 mm Hg)
- A. PaO_2 should be greater than 150 mm Hg when breathing 100% O_2

IV. Bradycardia (heart rate less than 25 beats/min)
- A. Cardiac arrhythmias: atrial or ventricular premature depolarizations

V. Inadequate anesthetic depth

VI. Nonrespiratory (metabolic) acidosis
VII. Nasal congestion and/or upper airway obstruction
VIII. Poor or prolonged recovery
IX. Excessive muscle weakness during recovery from anesthesia
A. Neuropathy and/or myopathy

Anesthetic Procedures and Techniques in Ruminants

23

"Moo may represent an idea, but only the cow knows."
MASON COOLEY

OVERVIEW

Local anesthetic techniques and sedation are frequently coupled with physical restraint to provide analgesia and immobility sufficient for surgery in ruminants. General anesthesia, when indicated, is accomplished using techniques that are similar to those used for horses but can be limited by regulations limiting anesthetic and analgesic drug use in ruminants. Potential hazards are regurgitation of rumen contents and bloat (distention of the rumen). Palpebral and ocular reflexes, eyeball position, and pupil size can be used to monitor the depth of anesthesia. Recovery from anesthesia is generally quiet and uneventful and does not routinely require assistance.

General Considerations

I. Preparation of ruminants for anesthesia and surgery
- A. Decrease rumen size and pressure before anesthesia
  1. Withhold food for 12 to 18 hours in large ruminants
  2. Withhold water for 8 to 12 hours in large ruminants, if possible
  3. Withhold food for 12 to 18 hours in sheep and goats; do not withhold water
  4. Withhold food for 2 to 4 hours in calves, lambs, and kids; when younger than 1 month of age, they are essentially monogastric and are less prone to regurgitation during anesthesia
- B. Side effects of withholding food are minimal
  1. Mild metabolic alkalosis is observed in healthy animals
  2. Bradycardia in adult cattle results from increased vagal tone
- C. Orotracheal and rumen tubes should be placed when appropriate to avoid bloat and aspiration of rumen contents

II. Most surgical techniques in cattle can be performed with local or regional anesthesia (see Chapter 5)
III. General anesthesia may be required when local or regional anesthetic techniques are inadequate or if dorsal recumbency is required for surgery; inadequate anesthesia predisposes the animal to stress, which may result in tachycardia and hypertension

Preanesthetic Evaluation

I. Preanesthetic evaluation is similar to horses (see Chapter 22)
   A. History
   B. Physical examination
   C. Basic laboratory tests
      1. Packed cell volume or hemoglobin
      2. Plasma total protein
      3. Serum glucose in neonates
      4. Other tests as suggested by physical examination

Preanesthetic Medication

I. Preanesthetic drugs are used to calm or sedate ruminants or to decrease the dose of more potent intravenous (IV) or inhalant drugs
II. Tranquilizers are not approved for use in food animals; drug residues in milk and meat products are problematic. Information about suggested withdrawal times is available from the Food Animal Residue Avoidance & Depletion Program's Food Animal Residue Avoidance Databank (FARAD) at www.farad.org. (Table 23-1)
III. Preanesthetic medications include (Table 23-2):
   A. Xylazine
      1. One tenth the IV dose used in horses: 0.02-0.04 mg/kg of body weight or less IV; 0.1 to 0.4 mg/kg intramuscular (IM). Ruminants may become recumbent after xylazine even at low doses.
      2. A moderate dose of 0.02 to 0.1 mg/kg IV generally induces recumbency and depresses or abolishes pharyngeal and laryngeal reflexes, thus allowing easy intubation and inhalant anesthesia without additional medication
      3. Xylazine (and other α_2-agonists) can cause increases in respiratory rate and decreases in respiratory compliance in sheep; pulmonary edema and hypoxemia may occur
      4. Side effects

TABLE 23-1 Approximate Withdrawal Times for Anesthetic Drugs in Ruminants

Drug	*Withdrawal Time* Meat	Milk	Comments
Diazepam	7 days	3 days	
Midazolam	7 days	3 days	
Xylazine	7 days	3 days	Withdrawal times established in Canada
Acepromazine	7 days	2 days	Withdrawal times established in Canada
Butorphanol	>3 days	>3 days	Believed to be rapidly eliminated
Morphine	>3 days	>3 days	Believed to be rapidly eliminated
Oxymorphone	>3 days	>3 days	Believed to be rapidly eliminated
Lidocaine	3 days	2 days	Rapidly eliminated in sheep
Mepivacaine	3 days	2 days	Rapidly eliminated in sheep
Ketamine	2 days	2 days	Short half-life in cattle (<1 hr) and swine (<3 hr)
Guaifenesin	>2 days	>2 days	Rapid elimination in ruminants
Inhalant Anesthetics			
Isoflurane	>3 days	>3 days	
Sevoflurane	>3 days	>3 days	

a. Respiratory depression
b. Cardiovascular depression
c. Rumen atony with bloat
d. Increased saliva production
e. Hyperglycemia from decreased plasma insulin
f. Diuresis
g. Decreased packed cell volume
h. Premature delivery in late pregnancy

5. Antagonists
   a. Nonspecific antagonists:
      (1) Doxapram 0.1 to 0.5 mg/kg IV can be used as a respiratory stimulant
   b. Specific antagonists (use with caution IV):
      (1) Atipamezole 20 to 60 μg/kg IV, IM
      (2) Yohimbine 0.12 mg/kg IV, IM
      (3) Tolazoline 0.5 to 2.0 mg/kg IM

B. Detomidine or dexmedetomidine
   1. Dose is similar to other species: 10 to 30 μg/kg IM
   2. Effects are similar to xylazine
   3. Antagonists: see section on xylazine

TABLE 23-2 Drug Dosages Used to Sedate and Tranquilize Ruminants (mg/kg)*

	Cattle		*Calves*		*Sheep*		*Goats*	
Drug	**IV**	**IM**	**IV**	**IM**	**IV**	**IM**	**IV**	**IM**
Acepromazine	0.03-0.05	0.05-0.1	0.03-0.05	0.05-0.1	0.03-0.05	0.05-0.1	0.03-0.05	0.05-0.1
Diazepam	0.2-0.5	0.5-1.0	0.2-0.5	0.5-1.0	0.2-0.5	0.5-1.0	0.2-0.5	0.5-1.0
Alpha-2 Agonists								
Xylazine	0.02-0.1	0.02-0.5	0.02-0.1	0.1-0.2	0.02-0.1	0.1-0.3	0.02-0.1	0.1-0.3
Detomidine	0.01-0.02	0.02-0.05	0.01-0.02	0.03-0.05	0.01-0.02	0.02-0.05	0.01-0.02	0.02-0.05
Medetomidine		0.02-0.05		0.02-0.05		0.01-0.03		0.01-0.03
Alpha-2 Antagonists†								
Yohimbine	0.1-0.2		0.1-0.2		0.1-0.5		0.1-0.2	
Tolazoline	1.0-2.0		1.0-2.0		1.0-2.0		1.0-2.0	
Atipamezole	0.02-0.05		0.02-0.05		0.02-0.05		0.02-0.05	

*Atropine, 00.5-0.1 mg/kg IV, and glycopyrrolate, 0.005-0.01 mg/kg IV, can be used to treat vagal-induced bradycardia but are only partially effective in reducing salivary secretions, which become more viscous and more difficult to remove from the airway, thus predisposing to airway obstruction.
†Doxapram 0.5-1.0 mg/kg is partially effective in stimulating respiration and reversing sedation produced by alpha-2 agonists.

C. Acepromazine (to produce a calming effect)
   1. Not frequently used because of prolonged elimination
   2. Dose: 40 to 90 μg/kg IM; 10 to 20 μg/kg IV
   3. Onset of tranquilization is within 10 to 20 minutes
   4. Duration of tranquilization is 2 to 4 hours

D. Atropine, glycopyrrolate
   1. Infrequently used, the duration of action of atropine is short
   2. Anticholinergics increase the viscosity of the saliva (without significantly decreasing the volume)
   3. Position the animal so that the pharynx is above the nose; saliva will run out of the mouth and not accumulate in the pharynx. Place an orotracheal tube with an inflatable cuff.
   4. Anticholinergics increase the incidence of bloat because of a decrease in intestinal motility and accumulation of gas

Induction (Table 23-3)

I. Guaifenesin
   A. Dose: 50 to 100 mg/kg IV in small increments until effective, followed by ketamine (1 to 2 mg/kg IV)
   B. 5% solution (50 mg/mL) in water or with 5% dextrose; more concentrated solutions (greater than 7%) may cause hemolysis
   C. Can be used in combination with xylazine, thiopental, ketamine, or Telazol

II. Xylazine-ketamine combination
   A. Dose: 40 μg/kg xylazine and 2 mg/kg ketamine IV
      1. Both drugs can be administered in the same syringe
      2. When given IV, immobilization occurs in approximately 45 to 90 seconds, supplying anesthesia for 20 to 30 minutes; standing recovery occurs 2 hours or more after the initial injection
      3. When given IM, induction time is 3 to 10 minutes; anesthesia and recovery times are increased
      4. Decreases heart rate, respiratory rate, and temperature; an apneustic respiratory pattern and salivation can be seen

III. Guaifenesin-ketamine-xylazine combination (called *triple drip*)
   A. Dose: 30 to 50 mg xylazine plus 500 mg ketamine in 500 mL of 5% guaifenesin given in small increments to effect, approximately 1 to 2 mL/kg IV; anesthesia can be continued at a rate of 2 mL/kg/hr

TABLE 23-3 Intravenous Anesthesia Drug Dosages Used in Ruminants (mg/kg)†

Drug	Cattle	Sheep	Goat
Propofol[~]	2-4	2-4	2-4
Ketamine	2-4	2-4	1-3
Telazol	2-4	2-4	2-5
Guaifenesin[§]	20-40		20-40
Ketamine	0.3-0.5		0.3-0.5
Xylazine[†]	0.04	0.04	0.02
Ketamine	1-2	1-2	1-3
Xylazine	0.05	0.05	0.04
Telazol	1-3	1-3	1-3
Diazepam	0.2	0.2	0.2
Ketamine	2-4	2-4	2-4
Xylazine	25 mg		
Guaifenesin[§]	500 ml 5%		
Ketamine	500 mg		
Telazol	500 mg		
Ketamine	250 (2.5 ml)		
Xylazine	250 mg (2 ml of 100 mg/ml)		

[~]Propofol infusion, 0.1-0.3 mg/kg/min, can be administered to supplement anesthesia. Be prepared for respiratory depression, apnea, and regurgitation that may occur in ruminants.
[§]Use dilute solutions (<6%) of gauifenesin in cattle, sheep, and goats.
[†]Use after preanesthetic medication.

1. All three drugs are soluble in water
2. Induction is gradual and generally uneventful but may require some physical restraint
3. Anesthesia can be safely maintained for up to 60 minutes; respiration may need to be assisted
4. Overdose causes apnea and hypotension
5. Formulation differs from that used in horses (lowered xylazine dose)

IV. Ketamine-guaifenesin combination (called *double drip*)

A. Dose: 500 mg ketamine in 500 mL of 5% guaifenesin given in small increments to effect, approximately 1 to 2 mL/kg IV; anesthesia can be continued at a rate of 2 mL/kg/hr

1. Both drugs are water soluble
2. Induction is gradual and generally uneventful but may require some physical restraint; compatible with prior administration of xylazine for sedation

3. Anesthesia is adequate for periods of 30 to 60 minutes; respiration may need to be assisted
4. Overdose causes apnea and hypotension
5. Can be used in calm animals

V. Ketamine-diazepam or ketamine-midazolam
- A. Ketamine (1 mL; 100 mg/mL) mixed 50:50 with diazepam (1 mL; 5 mg/mL); 0.05 to 0.10 mL/kg is used in small ruminants
- B. Ketamine (5 mg/kg) mixed with midazolam (0.2 mg/kg) is also used

VI. Ketamine or Telazol
- A. Dose: ketamine, up to 2 mg/kg IV or 2 to 7 mg/kg IM; Telazol, 1 to 4 mg/kg IV or 2 to 6 mg/kg IM
- B. Previous administration of xylazine (0.1 to 0.2 mg/kg IM) decreases ketamine or Telazol dose by one half
- C. Produce excellent, short-term (20 to 30 minutes) surgical anesthesia
- D. Ocular, pharyngeal, and laryngeal reflexes are depressed
- E. Compatible with inhalant anesthetics
- F. Side effects
  1. Respiratory depression
  2. Hypotension

VII. Using a face mask with an inhalant anesthetic is discouraged because of the potential for regurgitation. Masking should be limited to small ruminants.

Orotracheal Intubation

I. Orotracheal intubation should be performed immediately after the induction of anesthesia

II. Procedure
- A. A dental speculum or mouth gag can be placed in the mouth
- B. Method 1: insert an arm into the oral cavity of the adult cow, reflect the epiglottis forward manually, and guide the endotracheal tube into the larynx
- C. Method 2: extend the animal's head and neck and gently advance the tube into the trachea during inspiration (blind intubation)
  1. Blind intubation is more difficult in ruminants than in horses
- D. Intubation may be facilitated by a long-blade laryngoscope and endoscopic light (Fig. 23-1)

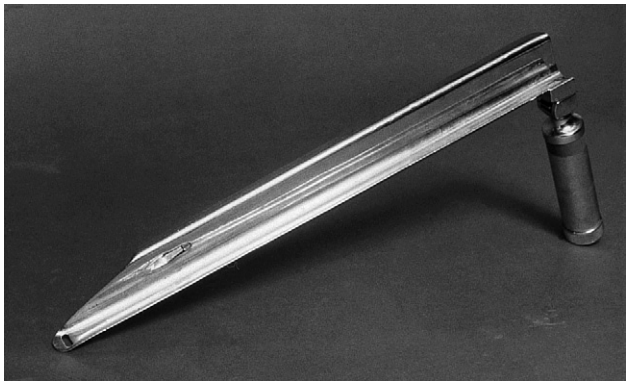


FIG. 23-1. Orotracheal intubation in cattle, sheep, and goats is facilitated with a long-blade laryngoscope.

E. In small ruminants, a long, small-diameter dowel made of aluminum or plastic may be placed into the trachea; the orotracheal tube can then be passed over it (Fig. 23-2)
F. Intubation should be performed quickly to avoid regurgitation and aspiration of fluid
G. A tracheostomy may be performed if necessary

Maintaining Anesthesia

I. Total IV anesthesia (Table 23-3)
A. Triple drip (see guaifenesin-ketamine-xylazine combination)
II. Inhalant anesthetic drugs produce general anesthesia effectively, particularly for prolonged surgical procedures
III. Analgesia (Table 23-4)
A. Butorphanol 0.1 mg/kg IM, 0.05 to 0.1 mg/kg IV
B. Morphine 0.04 to 0.10 mg/kg IM, 0.04 to 0.08 mg/kg IV
IV. Induction is completed with 2% to 4% isoflurane, or 4% to 6% sevoflurane
V. A surgical plane of anesthesia may be maintained at 1% to 2% isoflurane, or 3% to 4% sevoflurane
VI. Ventilate to minimize respiratory acidosis for procedures longer than 1 hour or if blood carbon dioxide tensions ($PaCO_2$) are greater than 60 mm Hg

Monitoring

I. The position of the eyeball provides a useful guide to anesthetic depth

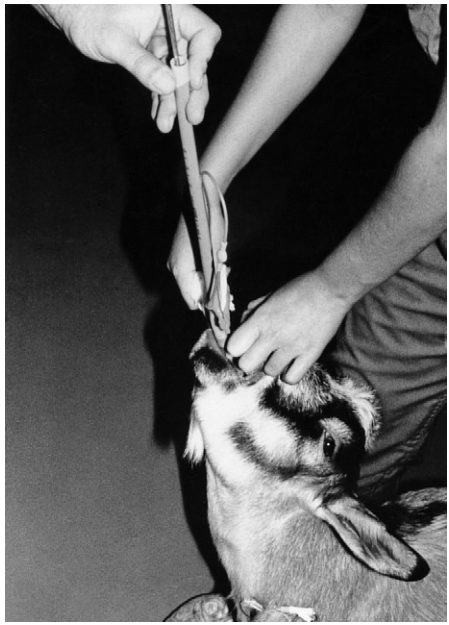


FIG. 23-2. A long aluminum dowel (stylet) can be placed in the trachea and the endotracheal tube slid over it to orotracheally intubate smaller ruminants (sheep, goats). The head and neck should be extended.

TABLE 23-4 Analgesic Drugs Used to Treat Pain in Ruminants (mg/kg)

Drug	Cattle	Sheep/Goat
Aspirin	100 PO q12h	100 PO q12h
Phenylbutazone	NR	10 PO
Flunixin meglumine	1.0 IM	1.0 IM
Butorphanol	0.005 IM	0.005 IM
Buprenorphine	NR	0.005 IM q12h
Meperidine	2.0 IM	0.5 IM
Morphine	NR	≤10 mg IM total dose
Oxymorphone	0.005 IM	0.005 IM
Xylazine	0.1 IM	0.05-0.1 IM

NR, not recommended



FIG. 23-3. The bovine eye rotates ventromedially during light stages of anesthesia.

A. Ocular reflexes are good indicators of anesthetic depth; the corneal reflex should be present throughout anesthesia; the palpebral reflex is depressed by inhalant anesthesia
B. The eyeball rotates medioventrally when the animal is in a light surgical plane of anesthesia (Fig. 23-3)
C. The iris and pupil are centered when the animal is in a deep surgical plane of anesthesia or awake
D. Dilated pupils are a sign of anesthetic overdose when using inhalant anesthesia
E. The auricular artery, located on the dorsal surface of the ear, can be cannulated to monitor arterial blood pressure

II. See Chapters 14 and 15 for more information on monitoring
III. Administering fluids (see Chapter 16)

Recovery

I. Provide 100% oxygen for 5 to 10 minutes until it is necessary to disconnect from the anesthetic machine
II. Leave the endotracheal tube in place with the cuff inflated until laryngeal reflexes return to prevent aspiration of regurgitated material
III. Position the animal's head (nose down) to allow drainage before the endotracheal tube is pulled

IV. The orotracheal tube can be removed with the cuff inflated
V. Pass a stomach tube if the animal is bloated to decompress the rumen before removing the endotracheal tube
VI. Ruminants may be less likely to regurgitate if placed on their right sides or in sternal recumbency
VII. Ruminants do not usually require assistance during recovery

Common Anesthetic Problems

I. The most frequently encountered problems associated with sedation and general anesthesia include the following:
  A. Regurgitation
  B. Bloat
  C. Inadequate oxygenation
  D. Respiratory depression and apnea
  E. Aspiration of rumen contents
  F. Injury

II. Regurgitation is caused by parasympathetic effects on reticular contractions and the pharyngoesophageal and gastroesophageal sphincters
  A. Anesthetic drugs increase the risk of regurgitation:
    1. Relaxation of the pharyngoesophageal sphincter
    2. Relaxation of the gastroesophageal sphincter
    3. Depression of the swallowing reflex
  B. Recumbency increases the risk of regurgitation by increasing abdominal cavity pressure
  C. Rumen tube can be placed to avoid aspiration and reduce bloat

24 Anesthetic Procedures and Techniques in Pigs

"I learned long ago, never to wrestle with a pig. You get dirty, and besides, the pig likes it."
GEORGE BERNARD SHAW

OVERVIEW

Anesthesia of pigs is a unique challenge. No approved anesthetic drugs are marketed for use in swine in the United States. Swine have few superficial veins that are easily accessible, other than those on the dorsal surface of the ear; ear veins may be difficult to use because of prior identification and tagging procedures. Most chemical restraining drugs are administered intramuscularly (IM). Pigs are difficult to orotracheally intubate because of their small oral cavities, large tongues, long soft palates, and the presence of a pharyngeal diverticulum. Respiratory depression and elevated body temperature may occur after sedation and general anesthesia. Respiratory depression can be caused by the combined respiratory depressant effects of anesthetic drugs and the limited expansion of the chest wall because of abnormal body positioning and body fat. Elevations in body temperature occur because of the relatively low body surface area to body mass ratio, the relative absence of effective sweat glands, and inefficient thermoregulatory mechanisms. Hyperpyrexia and malignant hyperthermia can occur in genetically predisposed pigs and is triggered by intravenous (IV) drugs such as ketamine and inhalant anesthetics such as isoflurane. Physical restraint combined with sedatives, tranquilizers, and local anesthetic techniques, is commonly used to complete simple surgical procedures in pigs. General anesthesia with inhalant anesthetics provides excellent, stable anesthesia for prolonged surgical procedures.

General Considerations

I. Surgical preparation of the pig
   A. Obtain a history and complete a physical examination; pay particular attention to the respiratory system
   B. Withhold food for 6 to 10 hours in adult pigs
   C. Do not withhold water

D. Avoid stressing the pig; leave it with other pigs until it is sedate

II. Preanesthetic evaluation (see Chapter 2)
- A. Physical examination including determination of body weight
- B. Basic laboratory tests (hemogram, white blood cell count), if indicated

III. Injection sites
- A. IM injections should be made in the cervical region (neck)
- B. IV injections are administered in auricular veins

IV. Withdrawal times for medications
- A. All anesthetic drugs used in swine are "extra-label"
- B. Suggested withdrawal times are available from The Food Animal Residue Avoidance & Depletion Program's Food Animal Residue Avoidance Databank (FARAD) at www.farad.org

Preanesthetic Medications

I. Azaperone (availability is limited)
- A. Butyrophenone tranquilizer
- B. The most effective tranquilizer in pigs
- C. Dose: 2 to 6 mg/kg of body weight IM, use lower doses in older pigs
- D. Rapid onset: 5 to 10 minutes after IM
- E. Duration: 30 minutes after IM
- F. Large doses may induce deep sedation and hypotension

II. Diazepam
- A. Produces minimal sedation and muscle relaxation in pigs
- B. Dose: 0.2 to 5 mg/kg IM; 0.2 to 0.5 mg/kg IV

III. Midazolam (similar to diazepam)
- A. Dose: 0.1 to 0.5 mg/kg IV or IM; reportedly twice as potent as diazepam

IV. Xylazine
- A. Produces short-term effects in pigs. Pigs may lie down but are arousable.
- B. Dose: 1 to 2 mg/kg IM
- C. Effective in combination with ketamine with or without an opioid

V. Dexmedetomidine
- A. Produces bradycardia, hypertension, and respiratory depression
- B. Dose: 0.005 to 0.010 mg/kg IV or IM

C. Effective in combination with ketamine with or without an opioid
D. Expensive

VI. Acepromazine
A. Does not produce potent sedation; more effective when used in combination with xylazine
B. Dose: 0.1 to 0.2 mg/kg IV or IM

Anesthetic Procedures

I. Telazol-ketamine-xylazine
A. Formulation: reconstitute 500 mg of Telazol powder with 2.5 mL of xylazine (100 mg/mL) and 2.5 mL of ketamine (100 mg/mL)
B. Administer the combination IM at 1 to 2 mL/25 kg body weight; limit initial dose to 3 mL
C. Provides useful restraint and short-term anesthesia
D. Orotracheal intubation can be performed (mask with inhalant if required)
E. Compatible with inhalant anesthetics
F. Duration of action is 20 to 30 minutes; recovery occurs in 60 to 90 minutes

II. Dexmedetomidine-ketamine-butorphanol
A. Good sedation, most pigs become recumbent
B. Dosage: dexmedetomidine 0.02 to 0.04 mg/kg IM; ketamine 4 to 10 mg/kg IM; butorphanol 0.1 to 0.2 mg/kg IM or buprenorphine 0.005 to 0.010 mg/kg IM

III. Xylazine-ketamine
A. Dosage: 2 to 6 mg/kg xylazine IM, followed in 10 minutes with 10 mg/kg IM ketamine
B. Administered volume may be large
C. Analgesia and muscle relaxation occur within 5 minutes; lasts 10 to 15 minutes
D. Involuntary muscle movement may occur during the anesthetic period

IV. Xylazine-ketamine-guaifenesin
A. Dosage: 500 mg xylazine plus 500 mg ketamine mixed in 500 mL 5% guaifenesin; given IV in small increments until effective, approximately 1 to 2 mL/kg IV
B. Advantages
1. Controlled induction
2. Stable hemodynamics
3. Good muscle relaxation

C. Disadvantages
   1. Respiratory depression may require assisted ventilation
   2. Intravenous access must be maintained (may be stressful)
   3. Salivation may be excessive

V. Xylazine-Telazol
   A. Dosage**:** xylazine 0.2 to 2 mg/kg IM followed in 5 minutes by Telazol 2 to 6 mg/kg IM
   B. Advantages
      1. Ease of administration
      2. Good analgesia and muscle relaxation
      3. Minimal cardiovascular depression
   C. Disadvantages
      1. Occasional respiratory depression
      2. Light plane of anesthesia
      3. Short duration of action; may need to be supplemented
      4. Pigs may remain drowsy for 24 hours
      5. Increased salivation

VI. Lumbosacral epidural or spinal anesthesia is commonly used in pigs (see Chapter 5)
   A. Minimal systemic effects and minimal effect on the fetuses during cesarean section
   B. Disadvantages include lack of unconsciousness, necessitating sedative administration or physical restraint of the forelimbs
   C. A 3- to 12-cm, 18-gauge spinal needle is used to facilitate administration of 2% lidocaine
      1. The dose varies from 0.04 to 0.10 mL/kg, with the higher dose providing anesthesia cranially to the paralumbar fossa; spinal doses are one half of epidural doses

VII. Inhalant anesthesia
   A. Inhalant anesthetics (isoflurane, sevoflurane) are used for short procedures if the animal will tolerate mask induction
      1. Provides excellent muscle relaxation and analgesia and little to no residual effects
      2. Well tolerated by most pigs
   B. Inhalant anesthetics are used to maintain anesthesia after induction with other drugs
   C. Inhalant anesthetic drugs (Fig. 24-1):
      1. Face mask
      2. Orotracheal intubation (preferred); pigs are more difficult to intubate than other species; a laryngoscope or long, rigid dowel rods can be used to help place the endotracheal tube (Fig. 24-2; Table 24-1)



FIG. 24-1. Facemasks and nasal endotracheal tubes are used as alternatives to orotracheal intubation in pigs.

TABLE 24-1 Endotracheal Tube Sizes for Pigs

Weight (kg)	Endotracheal Tube, mm (inside diameter)
<10	3-5
10-15	5-7
20-50	8-10
100-200	10-14
>200	16-18



FIG. 24-2. A laryngoscope with stylet to stiffen the endotracheal tube is frequently used to place an endotracheal tube in the trachea of pigs. The stylet should be advanced about 2 to 3 cm into the trachea to ensure advancement of the endotracheal tube into the trachea.

a. Open the pig's mouth; grasp the tongue with a gauze sponge, and pull it out
b. Do not overextend the head; too much extension makes it more difficult to identify the arytenoid cartilages and may occlude the airway
c. Use a laryngoscope and spray lidocaine to desensitize the larynx
d. Advance a small-diameter rod (stylet) made of metal or plastic about 2 cm into the trachea
e. Advance the endotracheal tube over the rod; rotate the tube dorsally when it meets resistance (the tip may contact the pharyngeal diverticulum)

D. Advantages
1. Good control of anesthesia
2. Excellent muscle relaxation
3. Ease of administration

E. Disadvantages
1. Expensive equipment required
2. Not generally suited for field conditions
3. Inhalant anesthetics can induce hyperthermia in pigs

VIII. Analgesia

A. Most opioids provide excellent analgesia in pigs
1. Butorphanol 0.1 to 0.2 mg/kg IM
2. Morphine 0.05 to 0.1 mg/kg IM

Monitoring

- **I.** Monitoring anesthesia in pigs is similar to that for other species but peripheral pulses may be difficult to palpate (see Chapter 14); the auricular artery, located on the dorsal surface of the ear, can be cannulated to monitor arterial blood pressure
  - A. Doppler probe can be placed to detect arterial pulsations (use the tail or a forelimb)
  - B. Other potential monitors include electrocardiography, capnometry, pulse oximetry, and body temperature
- **II.** Signs of malignant hyperthermia
  - A. Extreme muscle rigidity
  - B. Tachypnea due to increases in $PaCO_2$
  - C. Increased temperature (more than 107° F); hot to the touch
  - D. Tachycardia, cardiac arrhythmias
  - E. Hypotension
  - F. Hypoxia, cyanosis
  - G. Metabolic acidosis
  - H. Myoglobinuria with the potential for renal damage
- **III.** Treating hyperthermia in pigs
  - A. Dantrolene: 2 to 6 mg/kg IV; 20 mg/kg by mouth
    1. Administer twice a day as a preventative in stress-susceptible pigs
  - B. Termination of anesthesia
  - C. Supportive treatment
    1. Chilled fluids
    2. Sodium bicarbonate
    3. Steroids
    4. Oxygen
    5. Hyperventilation
    6. Body cooling
    7. Exchange of anesthesia system; especially carbon dioxide absorbent

Recovery

- **I.** Place the pig alone in a well-ventilated and quiet environment
  - A. Do not place the pig in a pen with other pigs. Conscious pigs may cannibalize the anesthetized pig.
- **II.** Position the pig in sternal recumbency
- **III.** Administer oxygen and/or assist ventilation if necessary
- **IV.** Assess vital signs, especially temperature, periodically

Common Anesthetic Problems

I. Respiratory depression is a frequent sequel to the administration of sedative and anesthetic drugs in pigs
- A. Estimate the size of the pig's trachea before drug administration; it may be very narrow
  1. Have a variety of endotracheal tube sizes available
- B. Be prepared for respiratory emergencies
  1. Be prepared to do a tracheotomy
     a. No. 10 blade and scalpel
     b. Hemostat
     c. Cuffed tracheostomy tube
  2. Respiratory stimulants: doxapram, 0.2 to 0.5 mg/kg IV

II. Increases in body temperature are frequently associated with inhalant anesthesia in pigs
- A. The pig has a small body surface area relative to body mass
- B. The pig has relatively poor thermoregulatory mechanisms and relatively few active sweat glands
- C. Depolarizing neuromuscular blocking agents and inhalant anesthetics can trigger malignant hyperthermia
  1. Several strains of pigs (e.g., Landrace, Poland China) are genetically predisposed to malignant hyperthermia
  2. Dantrolene (2 mg/kg IV) is the only truly effective therapy for malignant hyperthermia
     a. Intravenous formulations are expensive
     b. Oral formulations are less expensive and can be given prophylactically

25 Anesthetic Procedures and Techniques in Camelids

"A camel is a horse designed by committee."
SIR ALEC ISSIGONIS

OVERVIEW

Camelids (llamas, alpacas, camels) are often tractable, thus physical restraint and local anesthetic techniques are frequently used to provide immobility and analgesia. General anesthesia techniques are similar to those for ruminants and horses. Regurgitation of compartment one (C1) of the stomach contents, similar to ruminants, and postoperative nasal congestion and associated respiratory distress postextubation are potential hazards associated with anesthesia. Close observation and monitoring of palpebral and ocular reflexes, eyeball position, and pupil size can be used to monitor the depth of anesthesia. Recovery from anesthesia is generally quiet and uneventful.

General Considerations

I. Preparation of camelids for anesthesia and surgery
- A. Decrease the size and pressure in C1 before anesthesia
  1. Withhold food for 12 to 18 hours in adult camelids
  2. Withhold water for up to 12 hours in adult camelids
  3. Do not withhold food or water in neonates to decrease the risk of dehydration and hypoglycemia
     - a. Animals younger than 1 month of age are essentially monogastric and rarely regurgitate during anesthesia
     - b. Cria (pronounced cree-ah) is the name for a baby camelid such as a llama, alpaca, vicuña, or guanaco
- B. Stomach tubes should be placed in the esophagus when appropriate to relieve gas pressure and avoid bloat and aspiration of C1 contents
  1. Camelids should be orotracheally intubated for procedures lasting more than 20 minutes
- C. Positioning is important to reduce regurgitation

1. Keep the animal's head elevated above the stomach if possible
2. Do not roll an anesthetized animal dorsally unless an endotracheal tube is placed
3. If regurgitation occurs, position the animal's head with the mouth below the level of the poll and ensure an open airway; stomach tubes can be placed in the esophagus to prevent aspiration

D. Place a jugular catheter
1. Camelids do not have a jugular furrow; location of the vein after occlusion of the vein is dependent upon palpation
   a. The skin over the neck of male camelids is thick
2. The carotid artery runs close to the jugular vein and is more easily palpated than in other species; confirm venous placement before drug administration

E. Obtain an accurate weight; estimating the animal's weight should be avoided when possible
1. Camelids vary in size from neonates weighing 8 to 20 kg, to adult llamas of up to 200 kg and camels weighing up to 500 kg

F. Care of the head and neck is important following sedation and induction of general anesthesia
1. Control the head and neck during induction and recovery, maintaining a position that is similar to that in the awake animal
2. Eyes are large and prominent, and should be lubricated and protected during anesthesia

II. Some surgical techniques in camelids can be performed with local or regional anesthesia (see Chapter 5) in combination with sedation

III. General anesthesia is required if local or regional anesthetic techniques are inadequate; light stages of anesthesia may predispose the animal to stress, which may result in tachycardia and hypertension

Preanesthetic Evaluation

I. Preanesthetic evaluation is similar to that in ruminants (see Chapter 23) (Table 25-1)

A. Complete history

B. Physical examination with determination of body weight

C. Basic laboratory tests

TABLE 25-1 Normal Values for Awake and Anesthetized Camelids

		Heart rate (bpm)	Respiratory rate (bpm)	Mean arterial blood pressure (mm Hg)	Temperature (°F)	Packed cell volume (%)	Total plasma protein (g/dL)
Llamas and alpacas	Awake	60-90	10-30	90-110	100.5-102	23-43	6.0-7.5
	Anesthetized	>35	>6	>60	>95	>20	>4

1. Packed cell volume or hemoglobin
2. Plasma total protein

Preanesthetic Medication

I. Preanesthetic drugs are administered to calm or sedate camelids or to decrease the dose of a more potent intravenous (IV) or inhalant anesthetic drugs
   A. The dose in alpacas for sedatives is often up to 20% more than that required in llamas

II. Tranquilizers are not approved for use in food animals; drug residues in meat products are problematic

III. Popular preanesthetic medications include the following drugs:
   A. Xylazine
      1. 0.1 to 0.9 mg/kg of body weight IV or intramuscularly (IM) for large camelids, 0.1 to 0.3 mg/kg for llamas
      2. Use low-concentration of xylazine (20 mg/mL)
      3. Side effects
         a. Cardiovascular depression (bradycardia)
         b. Respiratory depression
         c. Stomach atony with bloat
         d. Hyperglycemia from decreased plasma insulin
         e. Diuresis
         f. Decreased packed cell volume
      4. Antagonists
         a. Nonspecific antagonists:
            (1) Doxapram 1 to 2 mg/kg IV can be used as a respiratory stimulant
         b. Specific antagonists:
            (1) Atipamezole 10 to 20 μg/kg IV; 20 to 40 μg/kg IM
            (2) Yohimbine 0.12 mg/kg IV
            (3) Tolazoline 0.5 to 1.0 mg/kg IV
   B. Detomidine or medetomidine
      1. Dose is similar to other species: 10 to 40 μg/kg IM
      2. Effects are similar to xylazine
      3. Antagonists: see section on xylazine
   C. Acepromazine (to produce a calming effect)
      1. Not frequently used because of prolonged duration of effect
      2. Dose: 0.1 mg/kg IM; 0.025 to 0.050 mg/kg IV
      3. Onset of tranquilization is within 10 to 20 minutes
      4. Duration of tranquilization is 2 to 4 hours

D. Butorphanol
   1. Dosage is 0.05 to 0.20 mg/kg IM or IV
   2. Produces mild sedation and analgesia
E. Xylazine-butorphanol-ketamine combination
   1. Useful for aggressive/unmanageable camelids; avoid in debilitated animals or use lower doses
   2. These three drugs are water soluble and can be combined in the same syringe
   3. Add 100 mg (1 mL) xylazine and 10 mg (1 mL) butorphanol to 1 g (10 mL) ketamine; administer 1 mL per 18 kg in alpacas or 1 mL/23 kg in llamas
   4. Onset of recumbency is 3 to 5 minutes; duration is 30 to 40 minutes
F. Benzodiazepines
   1. Provide sedation and muscle relaxation
   2. Diazepam 0.05 to 0.1 mg/kg IV
   3. Midazolam 0.05 to 0.2 mg/kg IV or IM
G. Atropine, glycopyrrolate
   1. Not frequently used for the same reasons as for ruminants (see Chapter 23)
      a. Secretions become thick and are more likely to lead to upper airway obstruction
   2. Atropine sulfate: 10 to 40 μg/kg IM or subcutaneous may be useful in preventing bradycardia and hypotension during manipulation of viscera
   3. Glycopyrrolate 0.005 to 0.010 mg/kg IM or 0.002 to 0.005 mg/kg IV as an alternative to atropine

Induction

I. Xylazine-ketamine combination
A. Ketamine 4 to 8 mg/kg IM or 3 to 5 mg/kg IV; xylazine 0.4 to 0.8 mg/kg
   1. Both drugs can be administered in the same syringe
   2. Immobilization occurs within 90 seconds after IV administration
      a. Anesthesia lasts for 20 to 30 minutes; standing recovery occurs 2 hours or more after the initial injection
   3. Induction time is 3 to 10 minutes after IM administration; anesthesia and recovery times are increased
   4. Decreases heart rate, respiratory rate, and temperature; an apneustic respiratory pattern and salivation may occur

II. Ketamine-guaifenesin combination (called *double drip*)
   A. Add 500 mg ketamine to 500 mL of 5% guaifenesin and administer until effective, approximately 1 to 2 mL/kg IV for induction to anesthesia and 1 to 2 mL/kg/hr for maintenance of anesthesia
      1. Both drugs are water soluble
      2. Induction is gradual and generally uneventful but may require some physical restraint
      3. Drug overdose causes apnea and hypotension
      4. Can be used in calm animals

III. Ketamine-diazepam or midazolam
   A. Ketamine (1 mL; 100 mg/mL) mixed 50:50 with diazepam (1 mL; 5 mg/mL) 0.05 to 0.1 mL/kg
      1. Produces good, short-term (15 to 20 minutes) surgical anesthesia
      2. Midazolam is an alternative to diazepam: same dosage
   B. Side effects
      1. Salivation
      2. Hypoventilation
      3. Hypotension

IV. Telazol
   A. Dose: 0.75 to 1.5 mg/kg IV or 2 to 4 mg/kg IM
      1. Produces good, short-term (20 to 30 minutes) surgical anesthesia
      2. Recovery is prolonged with IM injection and longer than that seen after single ketamine dose
   B. Side effects similar to ketamine-diazepam combination

V. Propofol
   A. Dose: 1 to 3 mg/kg
   B. Side effects
      1. Respiratory depression, including postinduction apnea
         a. Be prepared to orotracheally intubate and ventilate
      2. Hypotension

VI. Masking down with an inhalant anesthetic (isoflurane, sevoflurane)
   A. Not typically performed in adult camelids because of their size and their propensity to spit when distressed
   B. Isoflurane at 2% to 3% or sevoflurane at 3% to 4% in neonates

Orotracheal Intubation

I. Intubation should immediately follow the induction of anesthesia

II. Several techniques are applied based on species and animal size
A. Adult camels: similar to adult cattle (see Chapter 23; Fig. 25-1, *A* through *C*)
1. A dental speculum or mouth gag should be placed in the mouth
2. Insert an arm into the oral cavity, reflect the epiglottis forward manually, and guide the endotracheal tube into

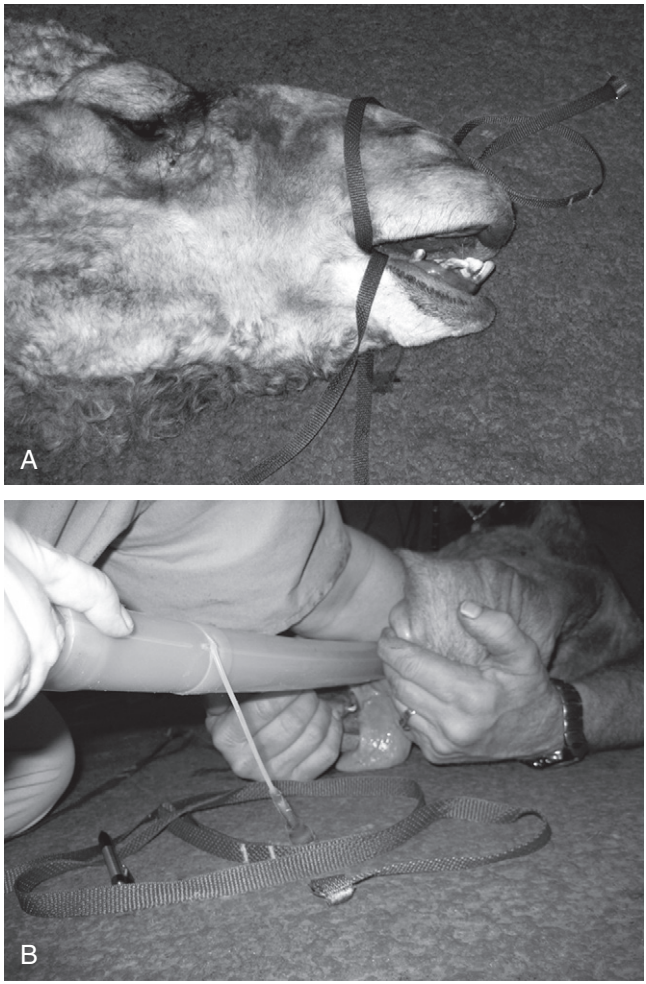


FIG. 25-1. Orotracheal intubation in adult camels. **A**, Rope or nylon ties can be placed to assist in opening the mouth if a mouth speculum will not fit. **B**, The anesthetist reflects the larynx with the left hand, and passes the tube into the trachea with the right hand, using the same technique as for adult cattle.

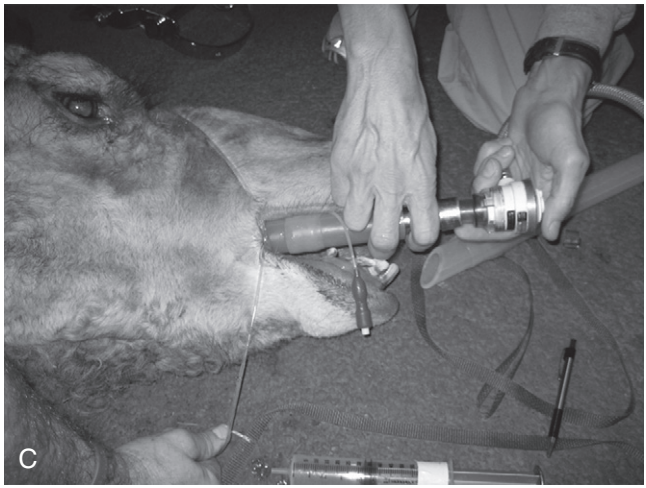


FIG. 25-1, cont'd C, Oxygen can be administered using a demand valve if needed after the tube is secured with the cuff inflated.

the larynx. The dental arcades are narrow, so the endotracheal tube must be protected. The soft palate is distensible and may make intubation more challenging than in adult cattle.

B. Small camels, llamas, and alpacas: similar to small ruminants (see Chapter 23; see Fig. 25-2, *A,* and *B*)
   1. The technique for orotracheal intubation is the same as that described for small ruminants
   2. Llamas and alpacas can be nasotracheally intubated. The technique involves gently passing the tube through the nasal meatus, directing it towards the larynx
      a. The larynx can be visualized with the aid of a laryngoscope. A bent stylet preplaced in the endotracheal tube may facilitate passage into the larynx.
      b. A nasotracheal tube can be left in place until recovery is complete

C. Orotracheal intubation should be done quickly and the tube cuff inflated to avoid regurgitation and aspiration of fluid

D. A tracheostomy may be performed if necessary

Maintaining Anesthesia

I. Total intravenous anesthesia

A. Double drip (see guaifenesin-ketamine combination)



FIG. 25-2. Intubation of a camelid. **A**, An assistant holds the head and neck in an extended position by grasping the upper lip and applying gentle forward pressure to the poll. **B**, A steel dowel is placed in the trachea and the endotracheal tube slid over it to facilitate intubation.

II. Inhalant anesthetic drugs produce excellent general anesthesia for prolonged surgical procedures
III. Induction is completed with 2% to 3% isoflurane or 4% to 5% sevoflurane
IV. A surgical plane of anesthesia may be maintained at 1% to 2% isoflurane or 3% to 4% sevoflurane
    A. Minimum alveolar concentration (MAC) for isoflurane in camelids is 1.05%
    B. MAC for sevoflurane in camelids is 2.3%
V. Anesthetized camelids generally ventilate better than ruminants
    A. Ventilation can be assisted or controlled to minimize respiratory acidosis for surgical procedures lasting longer than 1 hour or if blood carbon dioxide concentrations are greater than 60 mm Hg
VI. Analgesia
    A. Opioids
        1. Butorphanol 0.05 to 0.10 mg/kg slow IV or IM
        2. Morphine 0.04 to 0.10 mg/kg slow IV or IM
    B. Nonsteroidal antiinflammatory drugs
        1. Phenylbutazone 2 to 4 mg/kg orally once a day (SID); may consider administration of cimetidine 2.2 mg/kg concurrently
        2. Flunixin meglumine 1.1 mg/kg IV SID
            a. Avoid intraarterial injection
            b. Ulcerogenic: administer cimetidine concurrently
        3. Aspirin: 25 to 50 mg/kg orally twice a day

Monitoring

I. The position of the eyeball provides a useful guide to anesthetic depth (see Chapter 23)
    A. The palpebral reflex is depressed by inhalant anesthesia, but remains brisk in camelids compared with other species
        1. Occasional spontaneous blinking is not uncommon at light surgical planes of anesthesia. The "third-eyelid" will move across the eyeball during lighter stages of anesthesia.
    B. The auricular artery, located on the dorsal surface of the ear, can be cannulated to invasively monitor arterial blood pressure
        1. In camels that do not have prominent pinnae, peripheral arteries such as the dorsal metatarsal may be cannulated
II. Monitoring techniques are similar to other animal species (see Chapter 14)

III. Fluid administration is similar to other species (see Chapter 16)

Recovery

I. Camelids should be allowed to breathe 100% oxygen for several minutes before being disconnected from the anesthetic machine
II. Leave the endotracheal tube in place with the cuff partially inflated until the laryngeal reflex returns to prevent aspiration of regurgitated material
III. Position the camelid in sternal recumbency with the head and neck in a normal, neutral position (Fig. 25-3)
   A. Camelids frequently develop nasal congestion during anesthesia, and the head-up position allows venous drainage from the head to occur
   B. Sternal recumbency allows any gas that has built up in C1 to be eliminated
IV. Extubation
   A. Leave the cuff partially inflated while the endotracheal tube is removed
   B. Ensure that air is passing through the nostrils. If respiratory distress occurs (open-mouth breathing, dyspnea, cyanosis), oxygen can be administered by face mask



FIG. 25-3. Camelids are placed in sternal recumbency during recovery and the head and neck are supported in a neutral position.



FIG. 25-4. Placement of bilateral nasal tubes to alleviate nasal congestion after extubation.

1. Choanal atresia (CA) is a relatively common defect in alpacas, llamas, and other camelids (1 in 100 births); thought by many to be heritable
   a. A tracheotomy may need to be performed to establish an airway (see Chapter 28)
2. CA is a narrowing or blockage of the nasal airway by tissue. It is a congenital condition, meaning it is present at birth.

C. Place unilateral or bilateral nasal tubes if respiratory distress lasts more than a few minutes (Fig. 25-4)

V. Camelids rarely require sedation during recovery

Common Anesthetic Problems

I. The most frequently encountered problems associated with sedation and general anesthesia include the following:

A. Regurgitation (see Chapter 23)
B. Bradycardia
C. Respiratory depression and apnea
D. Postoperative respiratory distress
E. Pulmonary aspiration

26 Anesthetic Procedures in Exotic Animals

"'The time has come,' the Walrus said, 'to talk of many things.'"
LEWIS CARROLL

OVERVIEW

The number and variety of exotic animals being maintained as pets and for profit are increasing. Anesthesia for nontraditional species is accomplished for the most part by using the same techniques and drugs used in domestic animals. Because exotic species demonstrate idiosyncrasies and widely varying sensitivities to drugs, it is frequently necessary to make modifications. This chapter is an overview of the basic information needed to successfully immobilize exotic animals that are likely to be encountered by general practitioners.*

General Considerations

I. Preanesthetic considerations
  A. Discussions with owners
    1. Ensure that the client has realistic expectations
    2. Detail prognosis and risks; owners may not understand that exotic animals respond differently to immobilization than domestic animals

*For more detailed descriptions of chemical restraint and anesthesia in laboratory animals, including primates, refer to the following articles: Flecknell PA: *Laboratory Animal Anesthesia: a Practical Introduction for Research Workers and Technicians,* ed 2, San Diego, Academic Press, 1996; Kohn DF, Wixon SK, White WJ, Benson GJ, editors*: Anesthesia and Analgesia in Laboratory Animals (American College of Laboratory Animal Medicine Series)*, San Diego, Academic Press, 1997; Fox JG, Anderson LC, Loew FM, Quimby FW, editors: *Laboratory Animal Medicine (American College of Laboratory Animal Medicine)*, ed 2, San Diego, 2002, Academic Press; Heard D, editor: *Veterinary Clinics of North America*: *Exotic Animal Practice—Analgesia and Anesthesia*, 4(1), Philadelphia, Saunders, 2001; Longley L: *Anaesthesia of Exotic Pets,* Philadelphia, Saunders, 2008; Quesenberry KE, Carpenter JW, editors: *Ferrets, Rabbits and Rodents: Clinical Medicine and Surgery*, Philadelphia, Saunders, 2011.

3. Establish who will do the aftercare; owners may not be able to administer treatments to exotic pets
4. Discuss costs

B. Reduce the animal's stress; exotic animals have high sympathetic drive; excessive stress can induce complications that include myocardial arrhythmias, hypertension, and hyperthermia, which can result in death

C. Presurgical evaluation and animal selection
   1. Physical examination:
      a. Quiet observation of the animal in its cage can provide a significant amount of information (e.g., animal's awareness of and attention to its surrounding environment, body position and posture, skin or feather condition, respiratory rate)
      b. Contraindications to anesthesia
         (1) Abnormally slow recovery rate (the amount of time an animal needs to return to normal respirations after 2 minutes of physical restraint or pursuit); a normal amount of time is less than 3 to 5 minutes
         (2) Shock; septicemia; acidosis
         (3) Anemia or cyanosis
         (4) Prolonged clotting times
         (5) Cachexia or obesity
         (6) Animal has not fasted (if regurgitation is likely)
         (7) Severe weakness and central nervous system depression
         (8) Dehydration
         (9) Ascites
   2. Laboratory evaluation
      a. The volume of blood required for the sample should not exceed 10% of the animal's blood volume (e.g., the blood volume of a 30 g [body weight] gerbil is 2.3 mL and 10% of this volume is 0.2 mL)

Approximate Blood Volumes of Exotic Species

Type of Animal	Blood Volume (mL/kg)
Chicken	60
Reptile	90.8
Frog	95
Fish	17-28
Mouse	50-60
Rat	60
Gerbil	78
Syrian hamster	78
Guinea pig	60-65
Chinchilla	65
Rabbit	55-65
Ferret	60

b. Contraindications to anesthesia

(1) A blood transfusion may be needed if packed cell volume is low

Perilously Low Packed Cell Volumes in Exotic Animals

Type of Animal	Packed Cell Volume (%)
Avian	<25
Reptile	<17 to 20
Amphibian	<20
Rodent/lagomorphs	<20
Mustelid	<25
Felid	<15
Swine	<20
Camelid	<20

(2) Fluids (3 to 5 mL/kg of body weight/hr) should be supplemented during surgery

Perilously High Packed Cell Volumes in Exotic Animals

Type of Animal	Packed Cell Volume (%)
Avian	>50 to 60
Reptile	>50 to 60
Amphibian	>60
Rodent/lagomorphs	>55 to 60
Mustelid	>60
Felid	>50
Swine	>50
Camelid	>50

(3) Amino acid or plasma supplementation may be needed if total protein is less than 3 g/dL; refractometers and colorimetric tests frequently used at diagnostic laboratories for mammalian blood often register falsely low proteins in nonmammalian species; the biuret method is the most accurate in avian species
(4) Administer 5% dextrose or delay anesthesia if the glucose is low

Perilously Low Blood Glucose Levels in Exotic Animals

Type of Animal	Glucose (mg/dL)
Avian	<150
Reptile	30-100
Amphibian	<50
Rodent/lagomorphs	<80-100
Mustelid	<70-100
Felid	<80
Swine	<60
Camelid	<60

(5) Correct low calcium to greater than 8 mg/dL
(6) Correct low potassium to greater than 3.5 mg/dL

3. Further evaluation
   a. Oral/fecal Gram stains in nonmammalian species
   b. Bacterial culture and sensitivity testing
   c. Fecal/urinalysis
   d. Complete hemogram/biochemical profile
   e. Radiographs/ultrasound
   f. Clotting profile
   g. Electrocardiogram/echocardiography

II. Preanesthetic fasting
   A. Hypoglycemia can occur within a few hours in very small mammals

Time for Preanesthetic Food Withdrawal in Exotic Animals

Type of Animal	Time (hr)
Birds <100 g	0
Large psittacine bird	1 to 2
Raptor, ratite, fowl, waterfowl	12 to 24
Carnivorous reptile ingesting whole prey	>5 days
Reptile <200 g	2 to 4
Reptile 200 to 500 g	12
Reptile >500 g	24+

Time for Preanesthetic Food Withdrawal in Exotic Animals—cont'd

Type of Animal	Time (hr)
Amphibian	24
Fish	24
Rodent <200 g	0-2
Rodent >200 g	>6
Guinea pig	6-8
Ferret	3-6
Rabbit	0-24
Felid	24
Swine	24
Camelid	24 to 48

III. Maintaining homeothermy
- A. Hypothermia depresses the respiratory control system
  1. Small animals are predisposed to hypothermia; they lose heat rapidly as a result of high surface-area-to-volume ratios
  2. Ectotherms (reptiles, fish, and amphibians) do not generate their own heat; they require external heat sources to maintain their body temperature; hypothermia depresses the immune system and slows healing
  3. Hypothermia can result in brain damage, shock, electrolyte imbalances, and disseminated intravascular coagulation
     a. Well-insulated, small animals such as rabbits, chinchillas, water birds, and birds in winter plumage are susceptible to hyperthermia
     b. Ungulates are prone to malignant hyperthermia; stress, high ambient temperature, and high relative humidity during immobilization increase the likelihood of hyperthermia
- B. Methods of monitoring core body temperature (skin temperature is not reliable)
  1. Esophageal thermometer
  2. Rectal/cloacal thermometer
- C. Heat sources and retaining heat
  1. Always monitor heat sources to avoid iatrogenic burns and hyperthermia
     a. Skin temperature
     b. Surface temperature where the animal's body is in contact with a warmed surface
     c. Ambient temperature in incubators

2. Water-circulating heating pad
   a. Very safe
   b. High maintenance cost if punctured
3. Electric coil-type heating pads
   a. Likely to cause iatrogenic burns
   b. Inexpensive
   c. Should never be set on high
4. Incubators
   a. Must be preheated
   b. Useful before and after anesthesia
   c. Must be escape-proof
5. Hot water bottles
   a. Watch for overheating especially if warmed in a microwave
   b. Act as a heat sink after they cool
6. Forced warm air blankets
   a. Very safe
   b. Blankets warm immediate surroundings
   c. Animal's temperature must be monitored
7. Prevention of heat dissipation
   a. Plastic bag or aluminum foil
   b. Plastic bubble wrap
   c. Minimize the amount of hair clipped
   d. Use warm prep solutions and warm surgical flush
   e. Quickly cover the exposed surface with a drape
   f. Minimize the duration of anesthesia

IV. Fluids

A. Perioperative hypovolemia must be prevented to decrease postoperative morbidity and mortality

B. Preheat to 80° F to 95° F (26° C to 35° C) for animals weighing less than 1 kg and for all ectotherms
   1. Incubator
      a. Stable, consistent temperatures must be maintained
      b. Microbial growth may occur
   2. Warm water bath
      a. Stable, consistent temperatures must be maintained
      b. Water must be kept warm
   3. Microwave fluids
      a. Frequently have hot spots
      b. Should be well mixed
   4. Placing intravenous (IV) tubing in warm water bath
      a. Quick method to warm fluids in emergency
      b. Effluent temperature must be carefully monitored

TABLE 26-1 Sites for Parenteral Access or Injection in Birds and Small Mammals

Species	Sites for Parenteral Access or Injection	Comment
Bird	IM, IO, IV: basilic, jugular, medial metatarsal	
Rat and mouse	SQ, IM, IP, IO, IV: jugular, lateral tail	Lateral tail veins on mice are difficult to obtain blood from except by capillary action
Gerbil	SQ, IM, IP, IO, IV: lateral tail, saphenous, metatarsal	25-gauge needle
Hamster	SQ, IM, IP, IO (tibial crest), IV: lateral tarsus, cephalic, lingual, dorsal penile	IM: maximal volume 0.25 mL IO: use 22-gauge spinal needle IV: access is difficult, use 27- to 30-gauge needle
Chinchilla	SQ, IM, IP, IO, IV: femoral, cephalic, lateral saphenous, jugular, auricular, dorsal penile lateral abdomen, tail	IM: 23-gauge or smaller and maximum 0.3 mL IV: 25-gauge or smaller needle
Guinea pig	SQ, IM, IP, IO (trochanteric fossa), IV: marginal ear, medial saphenous, lateral saphenous, proximal to hock, dorsal penile, jugular	Self-mutilation can occur with IM injections; vascular access is usually difficult with short, mobile, friable veins
Rabbit	SQ, IM, IP, IO (trochanteric fossa), IV: marginal ear, cephalic, lateral saphenous, jugular	Blood clots quickly, external jugular is primary drainage for head (swelling occurs if catheter remains in place)
Ferret	SQ, IM, IP, IO, IV: cephalic, jugular, lateral saphenous, lateral tail	

IM, Intramuscular; *IO*, intraosseous; *IP*, intraperitoneal; *IV*, intravenous; *SQ*, subcutaneous.

5. Fluid heating devices (Hotline, SIS Level 1, Inc.)
   a. Warms IV fluids to above 104° F (40° C)

C. Administration (route) (Table 26-1)
1. IV or intraosseous (IO) administration is best; the humerus in all birds and the femur in many birds are pneumatic bones; placing IO catheters in these bones causes iatrogenic drowning
2. Subcutaneous (SQ) fluids (usually 5% to 10% of body weight) are given before induction of anesthesia to allow absorption and volume expansion

3. Intraperitoneal fluids
   a. More rapidly absorbed than SQ fluids
   b. Could cause peritonitis
   c. Must be warmed to body temperature
   d. Not in birds
   e. Not in pregnant animals
   f. Bladder should be expressed before administration
4. Colonic fluids
   a. Isotonic, warmed solution may be given as an enema
   b. Fluids are often absorbed more rapidly across the mucosa of the colon than from the SQ space

D. Fluid rates
   1. Standard maintenance: 40 to 100 mL/kg of body weight/24 hr; the higher end of the range is used for neonates, birds, and animals with high metabolic rates
   2. Intraoperative: 3 to 5 mL/kg/hr
   3. Shock: 5 mL/kg in 20 minutes and reevaluate

E. Fluid rate control
   1. Rates less than 10 mL/hr require an IV fluid infusion pump to ensure accuracy
   2. Rates of 10 to 50 mL/hr are accurately measured with inline flow controls or burette fluid chambers
   3. Rates greater than 50 mL/hr are accurately measured off of most fluid containers

F. Fluid choice (see Chapter 16)

G. Blood transfusion (see Chapter 16)
   1. Ethylenediamine tetra-acetic acid (EDTA) should not be used in small exotic animals to avoid hypocalcemia
   2. Heparin is the anticoagulant of choice for birds
   3. Birds can receive one interspecies or genera transfusion if a donor of the same species is not available, but survival of red blood cells over 24 hours is limited; intraspecific or at least intragenera transfusions are preferred
      a. Pigeons are the most common donors
      b. Transfusions should not be repeated for at least 3 weeks

H. Blood substitutes
   1. Oxyglobin (Biopure Corp.) can be used in most species as a blood substitute (10 to 30 mL/kg)

V. Premedication

A. If necessary, administer antibiotics to achieve adequate serum levels before induction of anesthesia

B. Select appropriate preanesthetic medication

TABLE 26-2 Injectable Sedative and Analgesic Drugs for Avian Use

Drug	Dose
Atropine	0.01-0.02 mg/kg IV, 0.02-0.08 IM
Glycopyrrolate	0.01-0.02 mg/kg IV, IM
Alphaxalone	10-14 mg/kg IV
Buprenorphine	0.01-0.10 mg/kg IM
Butorphanol	0.1-4.0 mg/kg IM
Codeine	30 mg/kg IM
Fentanyl	0.2 mg/kg IM
Morphine	0.1-3.0 mg/kg IV, 2.5-30 mg/kg IM, SQ
Diazepam	0.05-0.15 mg/kgIV, 0.2-0.5 mg/kg IM
Midazolam	0.05-0.15 mg/kg IV, 0.1-0.5 mg/kg IM 7.0 mg/kg intranasally
Detomidine	12 mg/kg intranasally
Ketamine >1 kg	15-20 mg/kg IM
<1 kg	30-40 mg/kg IM
Ketamine/midazolam	20-40 mg/kg IM+ 4 mg/kg IM
Ketamine/xylazine	10-30 mg/kg IM+ 2-6 mg/kg IM
Ketamine/midazolam/xylazine	40-50 mg/kg + 3.65 mg/kg + 10 mg/kg intranasally
Propofol	10 mg/kg slow IV infusion until effective Up to 3 mg/kg increments for supplemental doses
Etomidate	10-20 mg/kg IM
Betamethasone	0.1 mg/kg IM
Dexamethasone	2-4 mg/kg IV, IM
Methylprednisolone	0.5-1.0 mg/kg (route?)
Prednisolone sodium succinate	0.5-1.0 mg/kg IV, IM
Ketoprofen	5-10 mg/kg IM, 2 SQ
Flunixin meglumine	1-10 mg/kg IV, IM
Phenylbutazone	3.5-7.0 mg/kg IV
Carprofen	2-10 mg/kg IM, 1 SQ

IM, Intramuscular; *IV*, intravenous; *SQ*, subcutaneous.

C. Birds (Table 26-2)
   1. Anticholinergics are not indicated because they make respiratory secretions more viscous
   2. Preanesthetics are rarely indicated if the bird is small enough to be manually restrained
      a. They may delay recovery
      b. They may depress respirations
      c. Diazepam/midazolam is the most efficacious and safe—0.05 to 0.15 mg/kg IV, 0.2 to

0.5 mg/kg intramuscularly (IM), 7.3 mg/kg intranasally
(1) Can be reversed with flumazenil 0.13 mg/kg
d. Detomidine 12 mg/kg intranasally
e. Combination of midazolam (3.6 mg/kg), xylazine (10 mg/kg), and ketamine (40 to 50 mg/kg) intranasally
3. Because their long legs are susceptible to trauma, ratites, storks, and long-legged wading birds weighing more than 15 kg may benefit from sedation before capture and/or restraint
a. Xylazine 0.2 to 0.4 mg/kg IM
b. Tiletamine-zolazepam (Telazol) 2 to 5 mg/kg IM

D. Reptiles
1. Anticholinergics make respiratory secretions more viscous
2. Preanesthetics are rarely indicated, except in large, aggressive, and/or venomous reptiles

E. Amphibians: preanesthetics are not routinely used

F. Fish: preanesthetics are not routinely used

G. Rodents, guinea pigs, and rabbits
1. Atropine or glycopyrrolate is useful for decreasing airway secretions and maintaining heart rate
2. Some rabbits have atropinase—use glycopyrrolate instead (see Chapter 3)
3. Acepromazine and diazepam are effective preanesthetics
4. Acepromazine is not recommended in gerbils, because it may potentiate seizures
5. Hamsters require up to 5 mg/kg of acepromazine
6. Combination of fentanyl and fluanisone (Hypnorm) produces sedation and immobilization for about 30 to 60 minutes; analgesic effects may persist

H. Mustelids (ferrets)
1. Anticholinergics are given as needed to maintain heart rate and decrease secretions
2. Diazepam or midazolam provides light tranquilization but no analgesia
3. Acepromazine provides light to moderate tranquilization but also no analgesia; should be avoided in hypovolemic or very sick animals
4. Xylazine or dexmedetomidine produces dose-dependent sedation, immobilization, and analgesia
5. Opioids potentiate sedation and provide analgesia; usually given in combination with other sedatives or tranquilizers

6. Ketamine produces dose-dependent sedation; muscle relaxation is poor if it is given alone

I. Felids
1. Preanesthetics are not routinely used
2. Anticholinergics can be used at standard domestic cat doses
   a. Atropine 0.02 to 0.04 mg/kg SQ, IM, IV
   b. Glycopyrrolate 0.005 to 0.010 mg/kg SQ, IM, IV

J. Pigs (see Chapter 24)

K. Camelids (See Chapter 25)

VI. Monitoring anesthesia

A. Generalities
1. Pulse rate and character: a decrease in heart rate to less than 80% of the stabilized rate after induction indicates that anesthesia should be lightened
2. Respiratory rate, volume, and character (e.g., apneustic)
   a. A decreasing respiratory rate or apneustic/erratic patterns indicate that anesthesia should be lightened
   b. Ectotherms and birds normally develop apnea at surgical planes of anesthesia; plan to administer positive-pressure ventilation at least two to six times per minute
3. Body temperature
   a. Body temperature can drop as much as 10° C in 15 to 20 minutes
4. The level of anesthesia
   a. Reflexes are a good index of anesthetic depth; the signs vary between the species
      (1) Auricular reflex is useful in rabbits

B. Equipment
1. Electrocardiogram modifications
   a. To protect delicate skin or to penetrate thick skin, attach clips to steel sutures or metal hub needles placed through the skin
   b. Attach clips to alcohol-soaked pads placed at the usual lead sites
   c. Wings are used for forelimb lead sites in birds
   d. Place one clip cranial and one caudal to the heart in legless animals
2. Doppler placement
   a. Over the heart in small animals
   b. Over a peripheral artery

(1) Birds: medial metatarsal, brachial
(2) Reptiles: tail artery
(3) Rodents/lagomorph: ear, femoral, saphenous, foot pad (do not shave feet)
(4) Mustelids: tail, foot pad, saphenous

3. Pulse oximeter
   a. Measures the percentage hemoglobin saturation with oxygen in addition to heart rate
   b. Placement: tongue, esophageal
      (1) Measures across any nonpigmented capillary bed
      (2) Mucous membranes are excellent sampling sites: oral or nasal mucosa, cloaca, or vulva
      (3) Measures through nonpigmented skin: ear, wing web, thin skin of flank or abdomen
4. Heart rate monitors must be suited for high heart rates and be able to read up to 350 beats/min in rabbits and more than 600 beats/min in mice
5. Respiratory monitors must be sensitive enough to detect small tidal volumes

Avian Anesthesia (less than 15 kg)

I. Attaining surgical anesthesia
A. Toe, tail, and cloacal pinches
B. Most birds have a slow third-eyelid response; the loss of this response in birds indicates that anesthesia should be decreased
C. Response is not present in response to pinpricks to the cere
D. Respirations are slow, deep, and regular

II. Anesthetic procedure recommendations (Tables 26-2 and 26-3)
A. Preanesthetic agents can be used if needed
B. Inhalant anesthesia is preferred over injectable anesthesia
   1. The safety and efficacy of injectable anesthetics vary among species and individual animals
   2. It is difficult to titrate the dose of injectable anesthetics; inhalants are preferred
   3. Injectable agents can be used for restraint for short diagnostic procedures, minor surgeries, or for induction to inhalant anesthesia
C. Oxygen flow rates
   1. Greater than 200 mL/min/kg in small birds
   2. 0.5 to 2 L/min
D. Use a nonrebreathing system for all birds weighing less than 7 kg

TABLE 26-3 Avian Anesthesia

Species	Drug	Intramuscular doses (mg/kg)
Birds >250 g	Ketamine	20-40
	Diazepam	1-1.5
Birds <250 g	Ketamine	30
Parakeet	Ketamine	30
	Xylazine	6.5
Cockatiel	Ketamine	25
	Xylazine	2.5
Amazon	Ketamine	10-20
	Xylazine	1-2
African Grey	Ketamine	15-20
	Xylazine	1.5
Cockatoo	Ketamine	20-30
	Xylazine	2.5-3.5
Macaw	Ketamine	15
	Xylazine	1.5-2
Hawk, Falcon	Ketamine	25-30
	Xylazine	2
Owl	Ketamine	10-15
	Xylazine	2
Great Horned Owl	Propofol	4.5 (induction) 0.48 mg/kg/min (maintenance)

1. Restrain the bird by hand or use toweling
2. Place the bird's head inside a clear plastic bag taped to the end of the Y- or T-piece while oxygen and inhalants are flowing or use a face mask
3. Hold the bird until it is relaxed and then maintain anesthesia with a mask or intubation

E. Endotracheal intubation is recommended for all birds
1. Birds weighing less than 100 g should be intubated for procedures longer than 30 minutes or for procedures involving the coelomic cavity; small face masks are commercially available or can be fashioned from 35- to 60-mL syringe cases and rubber gloves
   a. Very-small-gauge silicone endotracheal tubes sized 1.0 mm and 1.5 mm (internal diameter) are useful (noncuffed endotracheal tubes-silicone V-PAT-10, V-PAT-15; COOK Veterinary Products)
2. The glottis is easily visualized at the base of the tongue

a. The trachea is composed of nonexpansible, complete tracheal rings; cuffs are not recommended
b. Tissue swelling caused by tube-induced tracheitis can occlude the trachea in birds
c. Small endotracheal tubes can be fashioned from catheters, the hub end of butterfly catheters, or red rubber feeding tubes; the hubs of these items fit into adapters made for commercially available 3.5- to 4.5-mm endotracheal tubes
d. Making the tubes just long enough to ensure secure placement can minimize dead space
e. Tubes should be taped securely to the bird's beak to avoid the sensitive cere
f. Tubes should be monitored for occlusion; mucous plugs and kinking are common; always have a replacement tube immediately available

3. The caudal thoracic air sacs can be cannulated if the trachea is occluded
   a. In the dorsal flank at the site usually used for surgical sexing with a red rubber feeding tube or uncuffed endotracheal tube cut to 2 to 5 cm in length; suture the tube in place; use the tube in the same fashion as an endotracheal tube; use aseptic technique to prevent life-threatening airsacculitis
4. Birds do not tolerate apnea
   a. Positive-pressure ventilation is required at least two times per minute to assist self-ventilating birds; ventilate 8 to 25 times per minute in apneic birds, higher rates (30 to 40 breath/min) may be required for smaller species
   b. Tidal volume is approximately 15 mL/kg; do not exceed 15 to 20 cm of H_2O during inspiration
   c. Birds have no pulmonary reserve; air is stored in the air sacs, which have no gas exchange capability

F. Isoflurane and sevoflurane are the anesthetics of choice in birds (Table 26-4)
   1. Induction: isoflurane 3% to 4%; sevoflurane 4% to 5%
   2. Maintenance: isoflurane 0.5% to 2.5%; sevoflurane 3% to 4%
   3. Induction usually takes less than 5 minutes
      a. Induction is more rapid in birds than in mammals because of the cross-current system of the blood and air

TABLE 26-4 Minimum Alveolar Concentration (MAC) of Various Inhalant Anesthetics

Species	Inhalant	MAC (%)
Duck	Halothane	1.04
	Isoflurane	1.3
Chicken	Sevoflurane	2.21
Rabbit	Halothane	0.8
Ferret	Enflurane	1.99
	Halothane	1.01
	Isoflurane	1.52
Alpaca	Sevoflurane	2.33
Llama	Isoflurane	1.05
	Sevoflurane	2.29

capillaries in addition to the greater proportional surface area of the lung; this makes the gas exchange in birds more efficient

b. Small changes in the vaporizer setting can cause rapid and dramatic changes in the plane of anesthesia; monitoring the level of anesthesia is critical

c. Recovery is rapid (usually less than 5 minutes for a procedure less than 45 minutes); hold the bird in a towel until it is able to walk

d. Apnea is an important signal to lighten anesthesia immediately; cardiac arrest can occur immediately after the onset of apnea; the endotracheal tube should always be checked for occlusion

4. Nitrous oxide can be used in most species of birds because the air sacs are not a closed compartment
   a. Should not be used in birds with physiologic SQ air pockets (e.g., pelicans)

G. Injectable anesthetics (see Table 26-3)
   1. Accurate body weight in grams is critical
   2. Effects of injectable anesthetics vary significantly among species and individual birds
   3. Recommended doses are only guidelines
   4. Administer IM injections in the pectoral muscles only
   5. Use of ketamine alone produces poor relaxation and turbulent recoveries; should be used with benzodiazepines (diazepam, midazolam); ketamine does not produce acceptable anesthesia in most waterfowl, owls, and hawks

6. Xylazine, detomidine, and dexmedetomidine cause excellent muscle relaxation and produce calm recoveries, but they are significant respiratory depressants; avoid using them in ill birds; may not be recommended for use in pet birds
   a. Can be reversed with tolazoline 15 mg/kg, yohimbine 0.1 to 1.0 mg/kg, or atipamezole 5 to 10 μg/kg
7. Benzodiazepines have variable effects; when they are not overridden, they produce safe sedation and muscle relaxation; they decrease stress-induced cardiovascular changes during induction
   a. Can be reversed with flumazenil 0.05 mg/kg (half IV and half IM or SQ)
8. Propofol can be used in birds
   a. Severe respiratory depression and apnea may occur
   b. Dose for induction is 20 mg/kg; 3 mg/kg boluses are required to maintain anesthesia
9. The combination of ketamine with xylazine or a benzodiazepine given IM usually produces adequate anesthesia for minor procedures
   a. Diazepam 0.5 to 1 mg/kg; ketamine 10 to 50 mg/kg IM; use higher doses for smaller birds
   b. Xylazine and ketamine
   c. Tiletamine/zolazepam 4 to 25 mg/kg IM
      (1) Parakeet: 15 to 20 mg/kg IM
      (2) Duck: 5 to 10 mg/kg IM
   d. If a deeper plane of anesthesia is needed
      (1) After waiting 10 minutes, readminister one fourth to one half of the ketamine dose
   e. If the plane of anesthesia is still inadequate, postpone the procedure for 24 hours before attempting anesthesia again
10. Recovery from injectable anesthetics is variable, but it usually takes more than 45 minutes after a 45-minute procedure
11. Use one fourth to one half of the IM dose if administering drugs IV

H. Anesthetic emergencies
   1. Apnea
      a. Positive-pressure ventilation; if no endotracheal tube is available, lift and compress the sternum
      b. Flush system free of anesthetic gas; administer 100% O_2

c. Doxapram: IV, IO, or IM at 5 mg/kg
d. Reverse α_2-agonists and benzodiazepines
2. Cardiac arrest
a. Epinephrine 5 to 10 μg/kg IV, IO, or intratracheally
b. Lift and compress sternum (quick compressions)
c. See Chapters 28 and 29 for additional information on treating anesthetic emergencies

I. Recovery
1. Continue monitoring the bird until it has recovered
2. Provide warmth; continue after recovery as necessary, but hyperthermia must be avoided
3. Place the bird in a warm, dark, and quiet recovery area
4. Monitor hydration and energy needs
5. Reduce the incidence and severity of self-induced trauma
a. Wrap the bird in a towel to control its wings
b. If the bird panics, hold it until it completely recovers

J. Analgesia (see Table 26-2)
1. In contrast to domestic mammals, birds indicate pain in a less obvious manner and tend to respond to noxious stimuli with a fight-or-flight response and/or conservation-withdrawal response that may be difficult for practitioners to interpret
2. Pain-associated behaviors
a. Acute pain: wing flapping and/or vocalization, decreased head movement, increased heart and respiratory rate, and increased blood pressure
b. Prolonged pain: inappetence, inactivity, and a "puffed-up" appearance are often demonstrated

Avian Anesthesia (more than 15 kg; long-legged)

I. The same general principles apply as for smaller birds

II. Unless they are very weak, these birds are large enough to require chemical sedation before induction of inhalant anesthesia

A. Large ratites (ostriches) are extremely dangerous; they should never be approached from the front; a forward kick can disembowel a person

B. Using large sheets of wood as shields, herd large ratites into a corner or chute from the sides and rear (head first)

C. Long-billed birds, such as storks and herons, strike swiftly with their beaks; it is imperative that eye protection be worn; first restrain these birds from over the back by their wings and neck; a second person should then grasp and protect the

legs; if the likelihood of hyperthermia is low, the beak may be taped partially shut by placing padding between and over the upper and lower tips of the beak

D. If the head can be reached safely, hood it with soft material to help calm and restrain the bird; ensure that the mouth and nares are open to the air to decrease the likelihood of hyperthermia

E. Capture myopathy, compartmental syndrome, hyperthermia, and leg fractures resulting from violent recoveries are complications associated with anesthesia in large, long-legged birds
   1. Adequate padding, maintenance of blood pressure, and oxygenation during these procedures is critical
   2. Exertional myopathies can develop in long-legged birds, especially if their legs have been maintained in a flexed position for a long period during surgery or recovery
   3. Reduce the handling needed to administer sedatives to a minimum; keep the induction and recovery areas as quiet and dark as possible
   4. Well-padded induction and recovery areas are desirable; a recovery stall slightly larger than a recumbent bird often makes it feel secure; after the bird has completely recovered, the hood can be removed and the crate opened for the bird's release; give it time to stand on its own; if a bird becomes agitated before it is fully recovered, administer diazepam (0.1 to 0.2 mg/kg, IM)

F. If the bird has not fasted, carefully inflate the cuff on the endotracheal tube to prevent aspiration; regurgitation is common in birds that have not fasted

III. Injectable anesthetics are useful for short procedures and for induction of inhalant anesthesia

A. IV injections can be administered in the brachial veins in standing birds (e.g., ostriches and emus); some calm birds tolerate jugular injections; rheas have poor brachial veins but are small enough to be manually restrained for inhalant anesthesia after an IM sedative

B. Brachial, jugular, and medial metatarsal veins are excellent sites for indwelling IV catheters

C. Ratites (ostriches, emus, moas, kiwis)
   1. Xylazine 0.5 to 1 mg/kg IM, followed by ketamine 2 to 4 mg/kg IV after 15 minutes
   2. Xylazine 0.25 mg/kg and ketamine 2.2 mg/kg IV

3. Tiletamine/zolazepam 4 to 10 mg/kg IM
4. Tiletamine/zolazepam 2 to 6 mg/kg IV
5. Diazepam 0.2 to 0.3 mg/kg and ketamine 2.2 mg/kg IV

Reptile Anesthesia

I. Hypothermia (refrigeration)
Note: Hypothermia is discouraged due to poor control of "anesthetic" effects
A. Depresses bodily functions, including the immune system and delays healing
B. It is questionable whether it provides enough analgesia
C. Delays recovery from anesthesia
D. Preferred optimal temperature during before and after hypothermia
1. Temperate and aquatic reptiles: 25° C to 30°C
2. Tropical reptiles: 30° C or higher

II. Premedication (Table 26-5)

TABLE 26-5 Preanesthetics and Analgesic Drugs for Reptiles

Drug	Route	Dose (mg/kg)
PREANESTHETICS		
Glycopyrrolate	SQ, IM, IV	0.01-0.04
Acepromazine	IM	0.1-0.5
Medetomidine	IM, IV	0.05-0.10 (tortoises) 0.15-0.30 (aquatic turtles)
Atipamezole	IM, IV	0.5
Midazolam	IM	1.5-2.0
Ketamine	IM, IV	5-20 (in combination with α_2-agonist or benzodiazepine)
Tiletamine/zolazepam	IM	3.5-10
Isoflurane*	Inhaled	2%-3% (on vaporizer)
Sevoflurane	Inhaled	4%-5% (on vaporizer)
ANALGESICS		
Butorphanol*	IM	1
Buprenorphine*	SQ, IM, IV	0.4-1
Ketamine	SQ, IM, IV	10-100
Meloxicam*	IM, IV, PO	0.1-0.2 q 24 hr
Carprofen*	SQ, IM, IV	2-4 followed by 1-2 q 24-72 hr
Lidocaine (2%)*	Local infiltration	Toxic dose unknown, recommended <5 mg/kg
Bupivacaine (0.5%)*	Local infiltration	Toxic dose unknown, recommended <2 mg/kg

*Dose anecdotal or determined by extrapolation from other species.
IM, Intramuscular; *IV*, intravenous; *PO*, by mouth; *SQ*, subcutaneous.

A. Phenothiazines should be avoided because of their prolonged clearance
B. α_2-Agonists alone produce minimal to no sedation and questionable restraint; their combination with dissociative anesthetics produces chemical immobilization
C. Midazolam
   1. Midazolam 1.5 mg/kg IM sufficiently relaxes most red-eared slider turtles to allow manual extension of the head and neck and opening of the mouth without resistance
   2. Midazolam alone produces poor to no sedation in snapping turtles and painted turtles
   3. In combination with ketamine can produce more reliable sedation and anesthesia

III. Induction of anesthesia
A. Excitement is followed by loss of motor control; loss of the righting reflex is followed by muscle relaxation; surgical anesthesia is attained when toe, tail, and vent pinches do not elicit a withdrawal
B. Most reptiles with third eyelids retain this reflex; a decrease in heart rate to less than 80% of the stabilized rate indicates that anesthesia should be lightened; heart rate is often the only reliable indicator of a reptile's level of anesthesia; it should be carefully monitored
C. Most reptiles (less than 500 g) can be induced by a mask or chamber at 2% to 4% isoflurane; use IV or IO propofol to induce anesthesia in larger reptiles; follow this with isoflurane; nitrous oxide can be used for enhancing rate of induction and recovery and production of analgesia. Sedatives are useful iguanas and other reptiles with strong jaw tone.
   1. Watch for apnea
   2. Chelonians, aquatic squamates, and crocodilians can hold their breath for long periods of time; it can be difficult to extract a chelonian's head from its shell and open its beak; injectable sedatives are often required to allow intubation and positive-pressure respiration to maintain inhalant anesthesia; venomous or large, aggressive reptiles may require injectable anesthetics for safe restraint
      a. Dexmedetomidine dose 10 to 40 μg/kg
      b. Propofol 5 to 7 mg/kg in colubrid snakes; 10 to 12 mg/kg in birds; 12 to 15 mg/kg in chelonians; 5 to 14 mg/kg in lizards
      c. Ketamine: 20 to 60 mg/kg IM

d. Ketamine: 5 to 15 mg/kg IV, IO
e. Tiletamine/zolazepam: 10 to 40 mg/kg IM in squamates; 5 to 15 mg/kg IM in chelonians and crocodilians
f. Succinylcholine: for intubation only
   (1) No analgesia
   (2) Paralyzes muscles, including muscles of respiration
   (3) Intubate and assist respiration for approximately 1 hour after injection, sometimes longer
   (4) Do not repeat within 24 hours
   (5) 0.25 to 1.50 mg/kg IM in chelonians, crocodilians in front half of animal

D. Intubation (similar to birds)
1. The glottis is a slitlike opening between the arytenoid cartilages and located at the base of the tongue
2. The glottis is harder to see in chelonians
3. Crocodilians possess a pharyngeal membrane that allows them to breathe with a mouth full of food or water; this membrane must be pushed aside to see the glottis
4. In some crocodilians the trachea is bent in on itself; therefore the endotracheal tube does not advance as far as expected
5. The tracheal rings are complete in chelonians and crocodilians; the trachea is short; to avoid intubation of only one bronchus, use a very short endotracheal tube
6. All reptiles attaining surgical levels of anesthesia must be intubated; exceptional care is needed for reptiles weighing less than 100 g to prevent tube-induced tracheitis

E. Maintenance
1. Isoflurane (1% to 2%) or sevoflurane (2% to 4%) are the anesthetics of choice
2. Oxygen flow rates: 1 L/0.3 to 1 kg; 1 L/5 to 10 kg for larger reptiles
3. Ventilate the animal at least three to six times per minute
4. Maintaining body temperature is essential
5. Difficult to monitor anesthetic depth
   a. A surgical plane of anesthesia; decrease in muscle tone, obtunded palpebral and corneal reflexes, regular or even respiratory pattern

F. Analgesia (see Table 26-5)

G. Recovery
1. Recovery with isoflurane usually takes less than 20 minutes for procedures lasting less than 1 hour

2. Recovery may take hours to days with injectable anesthetics
3. Positive-pressure ventilation must be continued until the animal is breathing regularly on its own
   a. Some reptiles breathe when stimulated, but not on their own
   b. During recovery, reduce ventilation to two times per minute; room air or exhaled air may be used to increase the carbon dioxide concentration to stimulate respirations; be careful not to induce anoxia
4. Heat and fluids accelerate recovery times

H. Emergencies
1. Respiratory arrest
   a. Apnea is frequent; if the animal is stable, administer positive-pressure ventilation
   b. In turtles, extending and retracting the front legs can temporarily facilitate respirations while an endotracheal tube is being placed
   c. To reverse xylazine: yohimbine 1 mg/kg IV
   d. Doxapram: 5 mg/kg IV, IO, IM
2. Cardiac arrest
   a. Administer 100% oxygen
   b. Use chest compressions in reptiles without shells
   c. Epinephrine 5 to 10 mg/kg IV, IO, IC, intratracheally
   d. See Chapters 28 and 29 for further information

Amphibian Anesthesia

I. Indications
A. Any painful procedure
B. Diagnostic imaging

II. Preanesthetic considerations
A. See the general considerations section at the beginning of this chapter
B. Amphibians are commonly grouped with reptiles in veterinary literature, it is more appropriate to include them with fish when discussing anesthesia
C. If kept moist, amphibians can remain out of water for long periods
D. Significant respiration occurs across moist skin
1. Do not allow skin to completely dry out
2. Handle the animal with wet latex gloves or wet hands
3. Intubation may not be necessary unless surgical procedures require supplemental inhalant anesthesia

E. The dermis of amphibians acts as a semipermeable membrane and allows not only for cutaneous respiration but also for absorption of other substances with which it comes in contact
F. Some species of amphibians secrete a toxin from their skin; it is wise to wear gloves, although reports of toxicity in humans are rare
G. Withhold food from the animal 24 hours before anesthesia
H. Preanesthetic medications are not commonly used
I. Ectotherm
   1. Maintain adequate body temperature with external heat sources
   2. Hypothermia prolongs recovery and depresses the immune system
J. Animals weighing more than 100 g should be intubated (see avian anesthesia earlier in this chapter)

III. Stages of anesthesia
A. Similar to mammals
B. Erythema of ventral abdomen during induction
C. Abdominal respirations cease with heavy sedation, but pharyngeal (gular) respirations continue
   1. Cutaneous respiration in amphibians is adequate to prevent clinical hypoxia during anesthetic events
D. Corneal reflex is lost before loss of the withdrawal reflex
E. Normal values for heart rate and blood oxygen levels have not been published

IV. Anesthetic drugs (Table 26-6)

TABLE 26-6 Anesthetic Agents in Amphibians

Agent	Concentration	Comment
MS-222*	250-500 mg/L	Tadpoles and newts
	1-2 g/L	Frogs and salamanders
	2-3 g/L	Toads
Isoflurane†	3 mL/L	Topical bath
Isoflurane/K-Y Jelly/ water‡	0.025-0.0035 mL/g	Topical application to dorsum of body wall

*Solutions greater than 1 g/L should be buffered using sodium bicarbonate.
†Use a 25-gauge needle to spray isoflurane into water (beneath the surface).
‡Mix 3 mL isoflurane, 1.5 mL water, and 3.5 mL K-Y Jelly. Shake solution vigorously until uniform gel forms. Gel should be removed with moist gauze pad once anesthetic induction has occurred.

A. Tricaine methanesulfonate, MS-222 (Finquel MS-222)
   1. Routes
      a. Immersion baths; keep tank of untreated water for recovery tank
      b. Parenteral—IM or SQ; use sterile solution
   2. Dose is species-dependent
      a. Immersion bath: 250 mg to 3 g/L
      b. 100 mg/kg SQ or IM (0.1 mL/10 g body weight with a 1% solution)
   3. Induction takes 5 to 20 minutes
   4. Pharmacology
      a. Rapidly absorbed through the gills
      b. Rapidly metabolized primarily by the liver but also in the kidneys, blood, and muscle
   5. Recovery takes 10 to 30 minutes; keep skin moist with untreated water and maintain normal temperature
   6. Wide margin of safety
   7. Suppliers
      a. Argent Chemical Laboratories
         8702 152nd Ave NE
         Redmond, WA 98052
         1-800-426-6258
         www.argent-labs.com/
      b. Crescent Research Chemicals
         2810 S. 24th St. Suite #110
         Phoenix, AZ 85044
         1-480-893-9234
         www.aqualogy.com/crescent/

B. Isoflurane
   1. Use the unvaporized liquid form
      a. Inject directly into a water bath
      b. Mixed into a viscous solution with water-soluble lubricant (K-Y Jelly, Johnson & Johnson) and water and then apply topically
   2. Intubate and ventilate after masking the animal
      a. Induce at 3% to 4% for 5 to 15 minutes
      b. Maintain at 1% to 2.5%
      c. Keep skin moist and maintain normal temperature
      d. Isoflurane is a respiratory depressant; use intermittent positive-pressure ventilation
      e. Recovery takes 10 to 30 minutes; keep the animal warm and moist

3. Bubble the vaporized gas into water after induction with an induction chamber
4. Isoflurane may be irritating to amphibian skin

C. Ketamine
1. Good for diagnostics, but not surgery
2. 100 to 200 mg/kg SQ or IM
3. Reflexes remain intact
4. Induction takes 10 to 20 minutes
5. Recovery takes 20 to 60 minutes

V. Recovery

A. Recovery of amphibians from general anesthesia is relatively long when compared with fish

B. It is unimportant to not raise their body temperatures for rapid recovery because they are poikilothermic

Fish Anesthesia

I. Indications

A. Any painful procedure
B. Sedation during shipping
C. Diagnostic imaging
D. Stripping milt (eggs)

II. Preanesthetic considerations

A. See the General Considerations section at the beginning of this chapter

B. Obligate water breathers
1. Require oxygenated water moving over gills to oxygenate blood
2. Normal water flow pattern is through the mouth, over the gills, and out the operculum
3. Provide water flow during anesthesia by using frequent immersion or a small recirculating pump and airstone; a pump tube should be placed in the fish's mouth so that water flow is maintained across the gills

C. Exterior mucus layer is an important part of the integument
1. Use the least amount of restraint possible
2. Use wet latex gloves when handling the fish to minimize disruption to the mucus layer

D. Withhold food 12 to 24 hours before anesthesia

E. Have a recovery tank ready with water identical to the fish's preanesthetic conditions

F. Preanesthetic medications are not commonly used

G. Ectotherms

1. Maintain adequate body temperature with external heat sources
2. Hypothermia prolongs recovery and depresses the immune system

III. Stages of anesthesia

Stages of Anesthesia in Fish

Stage	Plane	Category	Fish Response
0		Normal	Normal
I	1	Light sedation	Decreased response to visual stimuli
I	2	Deep sedation	Voluntary swimming stopped, normal posture, no response to external stimuli
II	1	Light narcosis	Excitement, loss of balance
II	2	Deep narcosis	Equilibrium lost, normal respiratory rate responds to pain
III	1	Light anesthesia	Decreased respiratory rate, deep pain present
III	2	Surgical	Low respiratory rate, low anesthesia heart rate
IV		Medullary	Cardiac and respiratory collapse arrest

IV. Anesthetic agents (Table 26-7)

A. Tricaine methanesulfonate, MS-222; Finquel MS-222

1. The only anesthetic licensed for use in fish
2. Commonly used as an immersion bath; keep tank of untreated water for recovery bath
3. Dose is species-dependent; sedation is generally achieved at 20 to 50 mg/L, induction of anesthesia at 75 to

TABLE 26-7 Anesthetic Agents in Fish

Agent	Concentration	Comment
MS-222*	75-125 mg/L	Induction dose
	50-75 mg/L	Maintenance dose
Etomidate	2-4 mg/L	Minimum effective dose
	7-20 mg/L	Maximum safe dose
Clove oil	40-100 mg/L	Use 95% ethanol to create stock solution of 100 mg/mL
Isoflurane†	0.40-0.75 mL/L	Induction dose
	0.25-0.40 mL/L	Maintenance dose

*Solutions should be buffered using sodium bicarbonate. Lower doses are recommended for young fish and for medically compromised animals.
†Use a 25-gauge needle to spray isoflurane into water (beneath the surface).

125 mg/L, maintenance of anesthesia at 50 to 75 mg/L; the depth of anesthesia is controlled by switching from a water bath that contains an anesthetic to an untreated water bath
4. Acidic solution: buffer with imidazole or sodium hydroxide to normal tank pH
5. Rapid induction of 1 to 5 minutes
6. Rapid recovery of 10 to 15 minutes; to prevent hypoxia, keep water moving over the fish's gills
7. Wide margin of safety
8. Suppliers (see amphibian section)

B. Etomidate
1. The minimum effective dose ranges from 2 to 4 mg/L; the maximum safe dose ranges from 7 to 20 mg/L
2. At 4 mg/L, fish typically enter anesthesia within 90 seconds and recover within 40 minutes
3. More effective in alkaline water and higher water temperature but is not affected by total hardness

C. Clove oil
1. Popular for koi and trout
2. The active ingredient is eugenol
3. Add into the induction chamber water at 40 to 100 mg/L

D. Isoflurane
1. Not a preferred anesthetic agent
2. Liquid isoflurane can be added to water

V. Treating anesthetic overdose
A. Move the fish to untreated, oxygenated water
B. Increase gentle water flow over the gills
C. If spontaneous respirations do not occur in 2 minutes, assist respirations
1. Move the fish gently through the water
2. Slowly pump oxygenated water into the fish's mouth and across its gills

Rabbit and Rodent Anesthesia

I. Generalities
A. Rabbits, guinea pigs, and chinchillas frequently hold their breath and then take deep, rapid breaths when being masked down or induced in a chamber; this behavior can result in death if the concentration of inhalants is high; to reduce risk, do the following:
1. Use preanesthetics (diazepam or midazolam) with ketamine

2. Use nitrous oxide followed by an anesthetic agent
3. Use a low induction setting

B. Levels of anesthesia
1. Excitement phase
2. Loss of coordination
3. Muscle relaxation
4. Surgical anesthesia is attained when toe, ear, and tail pinches do not elicit a withdrawal (no or decreased reflexes)
5. Loss of corneal reflexes varies significantly among individual animals and anesthetic agents; a loss of these reflexes in an animal that previously had them indicates that anesthesia should be lightened
6. A decreasing respiratory or heart rate or abnormal breathing patterns are also indications to lighten anesthesia

II. Intubation (Table 26-8)

A. It is difficult to intubate rodents and lagomorphs because of their small size and long, thin oral cavities; laryngeal masks may be easier

B. Masks are effective for short procedures (Fig. 26-1)

C. Intubation techniques and considerations (Fig. 26-2)
1. Small endotracheal tubes clog and kink easily
a. Check tube patency with positive-pressure ventilation at least every 2 minutes
b. Have a replacement tube ready
c. If a tube is clogged, try to reposition or suction it; if the tube does not become patent, maintain anesthesia by mask or injectables or place a new tube

TABLE 26-8 Endotracheal Intubation: Equipment Required

Species	Body Weight	Endotracheal Tube Diameter
Rabbit	1-3 kg	2-3 mm OD
	3-7 kg	3-6 mm OD
Rat	200-400 g	18-12 gauge plastic cannula
Mouse	25-35 g	1.0 mm
Guinea pig	400-1000 g	16-12 gauge plastic cannula
Hamster	120 g	1.5 mm
Primate	<0.5 kg	Not reported
	0.5-20 kg	2-8 mm O/D
Pig	1-10 kg	2-6 mm O/D
	0.5-20 kg	6-15 mm O/D

OD, Outside diameter.

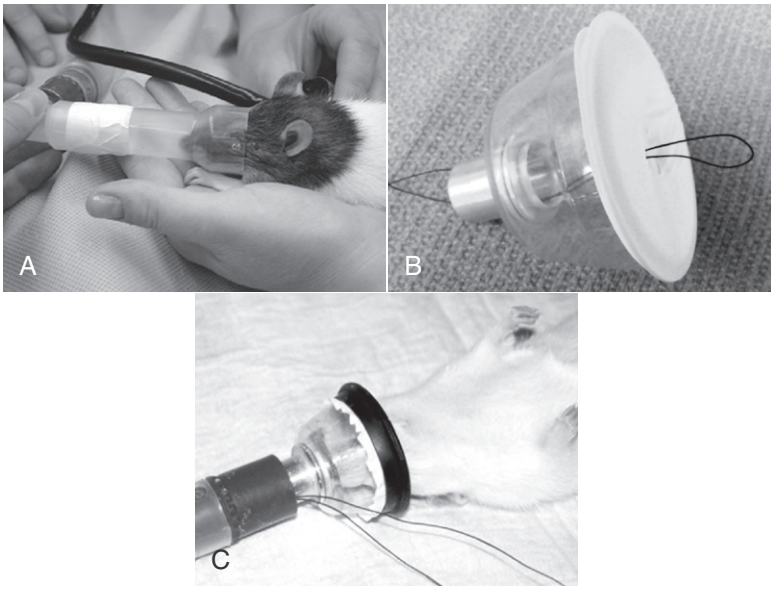


FIG. 26-1. A, Appropriate-sized masks and nose cones are commercially available or can be fashioned from syringe cases or other materials for induction and maintenance of anesthesia. The mask should have minimal dead space and a diaphragm so that a seal can be achieved on the animal's nose or neck (**B**). A piece of suture can be placed around the upper incisors and secured between the mask and breathing circuit (**B, C**).

2. Be careful not to create iatrogenic tracheitis
3. Prolonged, oral, or thoracic procedures require intubation
4. Oxygen flow
   a. 500 mL/min minimum
   b. 0.5 to 2.0 L/min/kg; 3 to 4 L/min maximum
   c. 1 L every 5 to 10 kg

D. Oral intubation: requires practice and skill (Fig. 26-3)
1. Best performed with sedate or lightly anesthetized animal that is relaxed with no chewing movements
2. Dorsal, lateral, or ventral recumbency
3. Extend the head and neck up
4. Keep animal straight
5. Grasp the animal's tongue and pull it forward or around the incisors
6. Stylet or tube is inserted into the oral cavity, around the incisors, and positioned towards the larynx. Advance the tube when condensation is observed in the tube during exhalation.

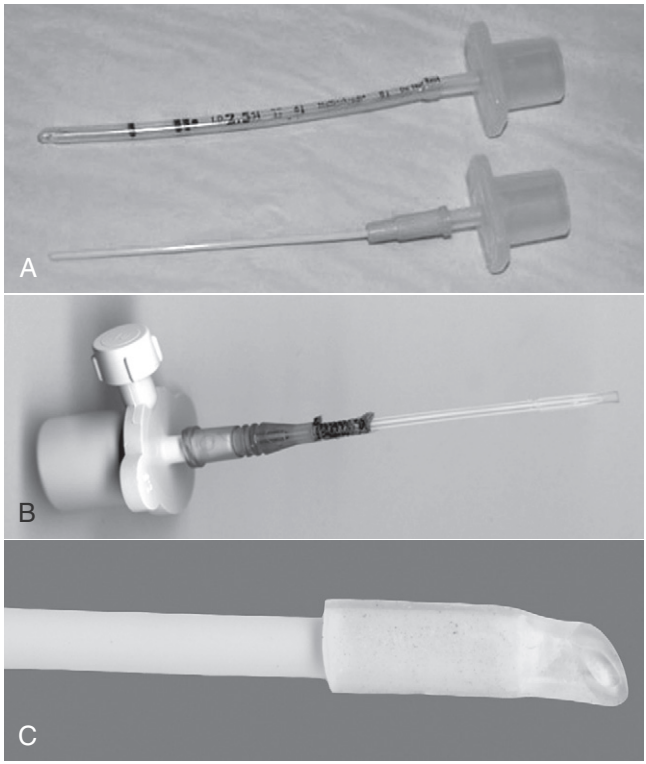


FIG. 26-2. A, Commercial endotracheal tubes are useful for larger mammals, but Teflon intravenous, red rubber, and urinary catheters can be used to orotracheally intubate very small mammals (**A, B**). A small piece of silicone tubing can be glued over the end of the intravenous catheter to minimize sharp edges (**B, C**).

7. A laryngoscope is helpful in larger animals (Fig. 26-4)
8. In rabbits, a small, rigid arthroscope or otoendoscope can be introduced into the mouth to allow visualization of the glottis; however, damage to the instrument by the animal's molars is possible with an arthroscope
9. Use of topical lidocaine can suppress laryngospasm
10. Repeated attempts at intubation can cause life-threatening hemorrhage and swelling

E. Retrograde technique:
1. Aseptically prepare the ventral neck
2. Pass an over-the-needle catheter into the trachea
3. Pass the catheter retrograde it through the larynx
4. Use the catheter as a stylet for the endotracheal tube

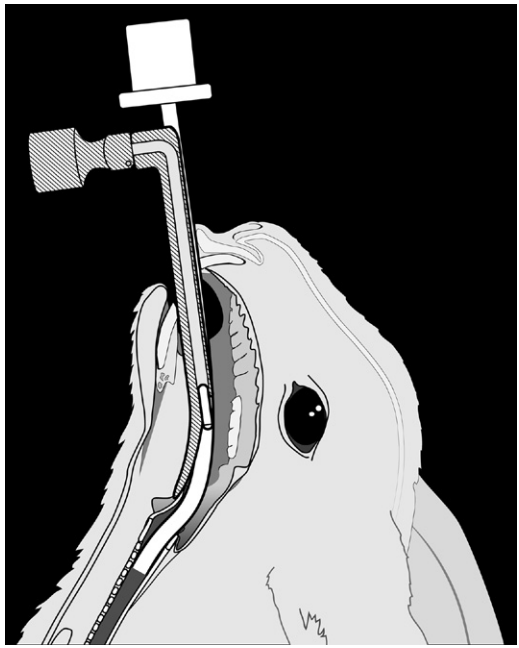


FIG. 26-3. A laryngoscope and a stylet to stiffen the endotracheal tube are frequently used to orotracheally intubate larger rabbits.



FIG. 26-4. Intubation of the rabbit using the blind technique. Provide fresh oxygen and anesthetic gas through a nasal mask during the procedure. Guide the tube to the larynx, listen for louder breaths and/or visualize water vapor in the tube (**A**), place one drop of 2% lidocaine via tomcat catheter through the endotracheal tube directly onto the larynx (**B**). Wait 60 seconds, then use the same approach for intubation (**C**). Correct placement of the tube is confirmed by visualizing of movement of water vapor in the tube, by the rabbit coughing, by auscultation of breath sounds in the lungs, and definitively by attaching a capnometer and seeing a characteristic capnogram.

5. Remove the catheter
6. In animals with fat necks, a "cut down" to the trachea may be required
7. Usually limited to the research setting

F. Induction
1. Isoflurane 2% to 3%
2. Sevoflurane 3% to 5%

G. Maintenance
1. Isoflurane 0.25% to 2%
2. Sevoflurane 2% to 3%
3. Use of nitrous oxide is similar to use in domestic mammals

H. Recovery
1. Isoflurane or sevoflurane take 5 to 15 minutes for surgeries that last less than1 hour
2. Keep the animal warm
3. Monitor the animal's hydration and energy needs

I. Analgesia (Table 26-9)

J. Injectable anesthetics (Table 26-10)
1. Results vary significantly among individual animals
2. Poor muscle relaxation and poor analgesia are the most frequent problems
3. Injectable anesthetics are most useful for diagnostics or minor procedures
4. Dosages listed are only guidelines (see Tables 26-9 and 26-10)
5. Barbiturates produce excellent muscle relaxation
   a. Their margin of safety is very low
   b. They are not recommended for use in pets
   c. Barbiturates are useful for euthanasia
   d. Pentobarbital: dilute to less than 10 mg/mL

K. Emergencies (see Chapters 28 and 29)

Ferret Anesthesia

I. Information in Chapters 8 and 21 is applicable to ferrets; ferret anesthesia is similar to that of domestic cats

II. Introduction

A. Sedate with diazepam or midazolam with ketamine

B. Mask induction is used for very ill ferrets to eliminate the side effects associated with many injectable anesthetics and for short procedures such as diagnostic tests; this allows the ferret to be returned to the owner quickly

TABLE 26-9 Preanesthetics and Analgesic Drugs for Rabbits and Rodents

Drug	Rabbit Dose (mg/kg)	Rodent Dose (mg/kg)	Mouse Dose (mg/kg)	Gerbil Dose (mg/kg)	Hamster Dose (mg/kg)	Guinea Pig Dose (mg/kg)
Atropine	0.08 SQ, IM, IV	0.05 SQ, IM	0.05 SQ, IM	0.05 SQ, IM	0.05 SQ, IM	0.05 SQ, IM
Glycopyrrolate	0.01-0.10 SQ, IM, IV	0.01-0.02 SQ, IM	0.01-0.02 SQ, IM	0.01-0.02 SQ, IM	0.01-0.02 SQ, IM	
Acepromazine	0.20-0.75 SQ, IM, IV	0.5-2.5 SQ, IM			5 IM, SQ	5 SQ, IP
Diazepam	0.5-5.0 SQ, IV	3-5 SQ, IM	3-5 SQ, IM	3-5 SQ, IM	3-5 SQ, IM	2-5 SQ, IP
Midazolam	0.5-5.0 IV, IM	3-5 SQ, IM	3-5 SQ, IM	3-5 SQ, IM	3-5 SQ, IM	2-5 SQ, IP
Xylazine	1-5 IV, IM	5-10 IM, IP	5-10 IM, IP	5-10 IM, IP	5-10 IM, IP	5-10 SQ, IP
Medetomidine	0.1-0.5 IM, IV	0.03-1.00 SQ	0.03-1.00 SQ	0.1-0.2 SQ	0.1 SQ	0.5 SQ
Aspirin	100 PO	100 PO	120 PO	—	—	87 PO
Carprofen	1.5 PO bid	5 SQ	—	—	—	—
Flunixin	1.1 SQ, IM q 12 hr	2.5 SQ, IM q 12 hr	2.5 SQ, IM q 12 hr	—	—	—

Ketoprofen	3 IM	—	—	—	—	—
Buprenorphine	0.01-0.05 SQ, IM, IV, 8-12 hr	0.01-0.05 SQ, IV or 0.10-0.25 PO 8-12 hr	0.05-0.10 SQ 12	—	—	0.05 SQ 8-12 hr
Butorphanol	0.1-0.5 IM, IV 4 hr	2 SQ 4 hr	1-5 SQ 4 hr	—	—	
Morphine	2-5 SQ, IM 2-4 hr	2.5 SQ 2-4 hr	2.5 SQ 2-4 hr	—	—	2-5 SQ, IM 4 hr
Oxymorphone	0.1-0.2 IM, IV	—	0.01 mL/30 g IP	0.5 mL/kg IM, IP	0.5 mL/kg IM, IP	1 mL/kg IM
Meperidine	5-10 IM	—	—	—	—	—
Fentanyl/fluanisone (Hypnorm)	0.5 mL/kg IM	0.4 mL/kg IM, IP	—	—	—	—
Fentanyl/droperidol	0.22 mL/kg IM		—	—	—	—

Note that considerable individual and strain variation in response may be encountered; therefore it is essential to assess the analgesic effect in each animal.
IM, Intramuscular; *IP*, intraperitoneal; *IV*, intravenous; *PO*, by mouth; *SQ*, subcutaneous.

TABLE 26-10 Rabbit and Rodent Anesthesia (mg/kg)

Drug	Rabbit Dose (mg/kg)	Rodent Dose (mg/kg)
Ketamine	15-30 IM	50-100 with sedatives
Ketamine/xylazine	35 + 5 IM	
Ketamine/xylazine/butorphanol	35 + 5 + 0.2 IM	
Ketamine/medetomidine	15-25 + 0.25-0.5 SQ, IM	
Ketamine/acepromazine	15-30 + 0.2 IM	
Ketamine/diazepam	10-20 + 0.5 IV	50 + 2.5 IP
Ketamine/midazolam	(as above)	(as above)
Tiletamine/zolazepam	5-25 IM	10-30 with sedatives
Fentanyl/droperidol		0.01-0.33 mL/kg SQ, IP
Fentanyl/fluanisone (Hypnorm)/diazepam	0.3 mL/kg IM + 2 mg/kg IV, IP	0.3 mL/kg IM + 2.5 mg/kg IP
Fentanyl/fluanisone (Hypnorm)/midazolam*	0.3 mL/kg IM + 2 mg/kg IP	2.7 mL/kg IP
Alphaxalone	6-9 IV	10-12 IV
Propofol	8-10 IV	10 IV

*Mixture of midazolam 1.25 mg/mL, fentanyl 0.079 mg/mL, and fluanisone 2.5 mg/mL. Midazolam and Hypnorm are each diluted with an equal volume of water before mixing.
IM, Intramuscular; *IP*, intraperitoneal; *IV*, intravenous; *SQ*, subcutaneous.

C. Monitoring the depth of anesthesia (see Table 26-9)
   1. Loss of pedal withdrawal reflex and muscle tone provides an indication of plane of anesthesia
   2. At a surgical plane of anesthesia, palpebral and corneal reflexes are lost

D. Because of their small size, ferrets require a nonrebreathing system; the oxygen flow must be two to three times the animal's minute ventilation (approximately 200 to 350 mL/kg/min)

E. Ferrets are easily intubated
   1. 2.0- to 3.5-mm internal diameter cuffed endotracheal tubes
   2. A laryngoscope is helpful

III. Inhalant anesthetics (see Table 26-4)

A. Isoflurane or sevoflurane
   1. Induce at 2.5% to 4%
   2. Maintain at 1% to 3%
   3. Recovery time is similar to that in cats

IV. Injectable anesthetics (Table 26-11)

V. Analgesia (Table 26-12)

VI. Emergencies (see Chapters 28 and 29)

TABLE 26-11 Anesthetic Drugs for Ferrets

Drug	Dose (mg/kg)
Alphaxalone	8-12 IV, 12-15 IM
Ketamine/acepromazine	25 + 0.25 IM
Ketamine/diazepam	5-25 + 0.5-2 IM
Ketamine/medetomidine	5-8 + 0.08-0.1 IM
Ketamine/xylazine	25 + 1-2 IM
Ketamine/butorphanol	15 + 0.2 IM
Ketamine/butorphanol/diazepam	15 + 0.2 + 3 IM
Ketamine/butorphanol/acepromazine	15 + 0.2 + 0.1 IM
Tiletamine/zolazepam	5-22 IM
Tiletamine/zolazepam/xylazine/ butorphanol	1.5-3.0 + 1.5-3 + 0.2 IM
Pentobarbital	25-30 IV, 36 IP
Propofol	5-8 IV
Urethane	1500 IV

IM, Intramuscular; *IP*, intraperitoneal; *IV*, intravenous.

TABLE 26-12 Premedicants and Analgesic Drugs for Ferrets

Drug	Dose (mg/kg)
Atropine	0.02-0.05 SQ, IM, IV
Glycopyrrolate	0.01 IV, SQ, IM
Acepromazine	0.1-0.3 IM, IV
Diazepam	0.5-3.0 SQ, IM
Midazolam	0.5-3.0 SQ, IM
Xylazine	1-2 SQ, IM
Medetomidine	0.08-0.20 SQ, IM
Ketamine	5-15 IM
Aspirin	200 PO
Flunixin	0.5-2.0 SQ; 12-24 hourly
Buprenorphine	0.01-0.03 SQ, IM, IV; 8-12 hourly
Butorphanol	0.4 IM; 4-6 hourly
	0.1-0.5 Q, IM, IV
Morphine	0.5 SQ, IM; 6 hourly
	0.2-2.0 SQ, IM
Oxymorphone	0.05-0.20 SQ, IM, IV
Pethidine (meperidine)	5-10 SQ, IM; 2-4 hourly
Fentanyl/droperidol	0.15 mL/kg IM

Note that considerable individual and strain variation in response may be encountered. It is essential to assess the analgesic effect in each animal.
IM, Intramuscular; *IV*, intravenous; *SQ*, subcutaneous.

Exotic Cat Anesthesia

I. Preanesthetic considerations
- A. See the general considerations section at the beginning of this chapter
- B. Withhold food from the animal for 24 hours; withhold water for 12 hours
- C. Respect the animal's strength
- D. Remote delivery (pole syringe, darting equipment) is often needed to ensure human safety
- E. Premedication is similar to that used in domestic cats but often is not needed
- F. Big cats usually require smaller doses (mg/kg) of anesthetics than smaller domestic cats
- G. Higher drug doses are needed for excited animals; create a calm and quiet environment for induction to anesthesia

II. Stages of anesthesia
- A. Similar to other mammals
- B. Sudden arousal of animals sedated with xylazine alone or dexmedetomidine and ketamine is possible; supplementation may be needed

III. Anesthetic agents
- A. Xylazine
  1. Rarely used alone because of the possibility of sudden arousal
  2. Significant respiratory depressant
- B. Ketamine
  1. Used alone for short procedures in small cats; 5 to 20 mg/kg IM
  2. Sole use often causes salivation and muscle rigidity
  3. Seizures have been reported in some species of exotic cats recovering from ketamine or ketamine-combination anesthesia; control with diazepam or midazolam
- C. Dexmedetomidine/ketamine IM
  1. Dexmedetomidine: 10 to 50 μg/kg
  2. Ketamine: 2 to 4 mg/kg
  3. Intubate and place on isoflurane or be prepared to supplement ketamine at 1 to 2 mg/kg IV if procedure is longer than 20 minutes
  4. At the conclusion of the procedure or after 20 minutes (whichever comes first), reverse dexmedetomidine with atipamezole (50 μg/kg IM) at five times the dexmedetomidine dose IM or IV

5. Bradycardia is common with dexmedetomidine; this is rarely a clinical problem, but animals should be supplemented with oxygen; this combination may not be appropriate for severely debilitated felines

D. Ketamine/xylazine combination IV
   1. Ketamine 8 to 10 mg/kg
   2. Xylazine 0.6 to 1 mg/kg
   3. Intubate and place the animal on isoflurane anesthesia if the procedure takes longer than 20 minutes

E. Ketamine/diazepam combination IV
   1. Ketamine 5 to 8 mg/kg
   2. Diazepam 0.1 mg/kg
   3. Intubate and place the animal on isoflurane anesthesia if the procedure takes longer than 20 minutes

F. Tiletamine/zolazepam (Telazol)
   1. A 500-mg vial can be reconstituted to a concentration of 100 to 500 mg/mL depending on the volume of diluent added (1 to 5 mL) for use in darting equipment
   2. Dose: 1.5 to 5 mg/kg IM for most species
      a. Sufficient for intubation
      b. Induces anesthesia in large felids in 2 to 5 minutes
      c. Intubate and place the animal on isoflurane anesthesia if the procedure takes longer than 20 minutes
      d. Snow leopards require a higher dose
      e. Excessive salivation is seen in some species; atropine can be combined to prevent this
      f. Recovery from anesthesia is smooth but prolonged compared with ketamine alone or ketamine combinations
      g. Delayed (3 to 10 days after immobilization) adverse drug reaction is seen in some Siberian and white tigers

G. Isoflurane or sevoflurane are the inhalant anesthetics of choice
   1. Small cats can be anesthetized in a chamber
   2. Face mask delivery can be used to supplement other anesthetics
   3. Dose
      a. Induce at 3% to 4%
      b. Maintain at 1% to 2% isoflurane; 2% to 3% sevoflurane
      c. Oxygen flow rate is 1 to 6 L/min
   4. Intubate the animal if the procedure takes longer than 20 minutes

IV. Treating anesthetic overdose
- A. Treat an overdose as an anesthetic emergency in domestic cats, but be prepared for arousal of the animal
- B. Xylazine can be reversed with yohimbine 0.1 mg/kg IM or IV or atipamezole 50 μg/kg IM, although results are not as dramatic as in other species
- C. Adverse tiletamine/zolazepam reactions in tigers have been treated with diazepam and dexamethasone
- D. Dexmedetomidine can be reversed with atipamezole at one half the volume of dexmedetomidine or 50 μg/kg IM or IV
- E. Tiletamine/zolazepam can be partially antagonized with flumazenil

CAMELID ANESTHESIA (LLAMAS, CAMELS, ALPACAS) (SEE CHAPTER 25)

Pot-bellied Pig Anesthesia

I. Preanesthetic considerations
- A. See the general considerations section at the beginning of this chapter
- B. Withhold food from the animal for 24 hours
- C. Warn the owner and the hospital staff that the pig may squeal when restrained—recommend wearing ear protection
- D. Sedate with dexmedetomidine 0.02 mg/kg, ketamine 3 to 7 mg/kg, and butorphanol 0.1 to 0.2 mg/kg; combined IM
- E. Orotracheal intubation can be challenging (see Chapter 23)
- F. Watch for hyperthermia, although it is less of a problem in pot-bellied pigs than in other pigs

II. Stages of anesthesia are similar to other mammals (see Chapter 9)

III. Anesthetic agents
- A. Isoflurane or sevoflurane
  1. Can be used as the sole anesthetic agent in small animals
  2. Agents of choice for inhalant anesthesia
  3. Deliver from a precision vaporizer with a face mask or an endotracheal tube
     - a. Induction: 3% to 4% isoflurane; 3% to 5% sevoflurane
     - b. Maintenance: 1% to 2% isoflurane; 2% to 4% sevoflurane
     - c. Oxygen flow rate: 2 to 3 L/min
- B. Tiletamine/zolazepam/ketamine/xylazine injectable combination
  1. Reconstitute a 500-mg vial of Telazol with 2.5 mL of 10% ketamine and 2.5 mL of 10% xylazine

2. Each milliliter of resultant mixture contains the following:
   a. 50 mg tiletamine
   b. 50 mg ketamine
   c. 50 mg zolazepam
   d. 50 mg xylazine
3. Dose
   a. Sedation: 0.006 to 0.01 mL/kg IM
   b. Surgical anesthesia and intubation: 0.018 to 0.024 mL/kg IM
   c. Requires 20 to 40 minutes to take effect
   d. Can be supplemented with 0.1- to 0.5-mL bolus in the auricular vein

C. Midazolam/dexmedetomidine/butorphanol
1. Midazolam 0.3 mg/kg IM
2. Dexmedetomidine 20 to 40 μg/kg IM
3. Butorphanol 0.3 mg/kg IM
4. Supplementation
   a. Intubate and maintain on isoflurane
   b. Propofol 1 mg/kg IV
   c. Ketamine 1 mg/kg IV
5. Antagonists
   a. Atipamezole 0.08 mg/kg IM or IV
   b. Naltrexone 0.05 to 0.1 mg/kg IM or IV
   c. Restrain the animal until it is coordinated

D. Telazol/dexmedetomidine/butorphanol
1. Telazol 0.5 mg/kg IM
2. Dexmedetomidine 20 to 40 mg/kg IM
3. Butorphanol 0.3 mg/kg IM
4. Supplementation (see section C4 above)
5. Antagonists (see section C5 above)

E. Provide supplemental oxygen to all immobilized pigs with nasal tube at 5 L/min

VI. Treating anesthetic overdose

A. If using isoflurane, turn vaporizer off and flush system
B. Administer oxygen
C. If xylazine or dexmedetomidine has been given, reverse with yohimbine 0.125 mg/kg IV or atipamezole 0.08 mg/kg IM or IV
D. If an opioid has been given, antagonize with naloxone or naltrexone 0.1 mg/kg IM or IV
F. Perform cardiopulmonary resuscitation as for other mammals

27 Anesthesia for Cesarean Section

"The hand that rocks the cradle is the hand that rules the world."
WILLIAM ROSS WALLACE

OVERVIEW

Anesthetic drugs administered to pregnant animals often depress the fetus. Generally, the effects of anesthetic drugs are more pronounced and longer lasting in the fetus than in the mother. Drugs that cross the placental barrier slowly, or not at all, are preferred. Anesthetic drugs may induce or inhibit parturition by altering uterine smooth muscle tone. This chapter describes the changes that occur in maternal physiology during pregnancy and the effects of anesthetic drugs in pregnant animals.

General Considerations

I. Pregnancy, especially the immediate preparturient period, causes significant alterations in maternal physiology
  A. Altered drug pharmacokinetics and pharmacodynamics
  B. Hemodynamic changes
    1. Increased heart rate
    2. Increased cardiac output
    3. Increased blood volume
    4. The weight of the gravid uterus can cause aortocaval compression when the animal is placed on its back; cardiac reserve is decreased because of increased cardiac work
    5. Central venous pressure and systemic blood pressure remain relatively unchanged but may increase during labor
  C. Changes in respiration
    1. The gravid uterus may restrict breathing by cranially displacing the diaphragm
    2. Breathing rate increases
    3. Decreased functional residual capacity (FRC)

II. Anesthetic considerations
  A. Provide optimal analgesia for surgery
  B. Prevent maternal hypoxemia and hypotension

C. Minimize fetal hypoxia and depression
D. Minimize postoperative maternal depression

Changes in Maternal Physiology in Advanced Pregnancy

I. Central nervous system (CNS)
A. Increased progesterone concentration decreases inhalant anesthetic requirement
B. Vascular engorgement decreases the size of the epidural space; a decreased volume of epidurally administered drug is required

II. Respiratory system
A. Alveolar ventilation is increased because of progesterone-induced increased respiratory center sensitivity to carbon dioxide
1. Increased respiratory rate and alveolar ventilation and decreased FRC result in a rapid alveolar rate of rise in inhalant anesthetics
a. FRC is decreased because of anterior displacement of diaphragm
B. Small airways constrict at higher lung volumes
1. Airway closure and decreased FRC cause greater ventilation perfusion mismatches, which may result in decreased oxygenation

III. Cardiovascular system
A. Maternal blood volume is increased by up to 30%
B. Packed cell volume and plasma-protein concentration are decreased
1. Relative anemia refers to the pregnant animal not tolerating blood loss as well as the nonpregnant animal
C. Cardiac output is increased 30% to 50% because of increases in stroke volume and heart rate
1. Animals with a history of heart disease may develop heart failure

IV. Gastrointestinal system
A. Placental gastrin secretion increases gastric acidity
B. The stomach is displaced cranially, and the tone of the lower esophageal sphincter is altered
1. Increases potential for regurgitation and aspiration pneumonia
a. A properly fitting cuffed endotracheal tube is essential

V. Other changes: decreased plasma cholinesterase (pseudocholinesterase)

A. Prolonged duration of action of succinylcholine
B. Prolonged duration of action of ester-linked local anesthetics (procaine)

Drug Transfer across the Placenta

I. Factors influencing drug transfer across the placenta
  A. Surface area and diffusion characteristics of the placenta
    1. The surface area of the placenta is large, and diffusion distance is small in all species
  B. Diffusion properties of drugs
    1. High lipid solubility increases diffusion (e.g., barbiturates, inhalants)
    2. Lower molecular weight increases diffusion
    3. Decreased degree of ionization and protein binding increases diffusion
  C. Relative maternal and fetal drug concentrations
    1. Bolus doses of drugs result in rapid transfer of drug to the fetus followed by rapidly declining maternal concentrations
    2. Continuous infusion, repeated bolus administration, and the administration of inhalant anesthetics result in elevated maternal drug concentrations and continual drug transfer to the fetus

Uteroplacental Circulation and Fetal Viability

I. Conditions that decrease circulating maternal blood volume can decrease placental perfusion resulting in fetal hypoxia and acidosis; this includes maternal dehydration, hemorrhage (hypovolemia), and drug-induced hypotension
  A. Dehydration
    1. Prolonged labor
    2. Concurrent disease
  B. Hemorrhage and shock
    1. Supine positioning: decreases venous return
    2. Surgically related hemorrhage
    3. Septic or endotoxic shock
  C. Anesthetic drugs can cause peripheral vasodilation and hypotension

Effects from Anesthetic Drugs Administered for Cesarean Section

I. Anticholinergics—drug effects
  A. Atropine crosses the placental barrier rapidly

1. Fetal tachycardia noted within 10 to 15 minutes of drug administration
2. Fetal disorientation or excitement may be caused by CNS effects of atropine

B. Glycopyrrolate does not cross the placental barrier in significant quantities because of its large molecular size and charge

C. Anticholinergics can reduce uterine contractile activity

II. Local anesthetic drugs

A. Local anesthetic drugs administered by any route cross the placental barrier
1. Drug effects depend on the total dose, the interval between final dose and delivery, and whether epinephrine is used
2. Clinically relevant doses of local anesthetics usually do not produce significant depression in the fetus

B. Lidocaine
1. Lidocaine is the preferred local anesthetic for cesarean section because of its relatively low toxicity
2. Detected in the umbilical venous blood of the fetus within 2 to 3 minutes
3. No correlation has been found between the degree of neonatal depression and the umbilical venous concentration of lidocaine

III. Preanesthetic drug effects

A. Drug effects: preanesthetic drugs reduce the amount of potentially more dangerous anesthetic drugs
1. Phenothiazines (acepromazine)
   a. Rapidly transferred into the fetal blood
   b. Clinical doses produce little to no apparent effect on the newborn
   c. α-Adrenergic blockade may produce hypotension resulting in decreased uterine blood flow and fetal hypoxia
   d. Decreased uterine tone
2. Benzodiazepines (diazepam, midazolam)
   a. Concentrations higher in fetal blood than in maternal blood
   b. Produce minimal respiratory and cardiovascular depression in the fetus and mother
   c. Duration of effect depends on redistribution away from the CNS

3. α_2-Agonists (xylazine, detomidine, dexmedetomidine, romifidine)
   a. Marked respiratory depression in both the mother and fetus
   b. Use in low doses and be prepared to administer an antagonist to the newborn (yohimbine, tolazoline, atipamezole)
   c. α_2-Agonists increase uterine tone and pressure in cattle; may be abortifacients; effects in other species are less defined
4. Opioids
   a. Frequently used as preanesthetic medication for sedation and analgesia; some (e.g., morphine) are administered epidurally
   b. Readily cross the placenta
   c. Opioid concentrations may be higher in the fetus than in the mother
   d. Moderate maternal doses do not produce serious CNS depression; the effect can be reversed by opioid antagonists (naloxone)
   e. Naloxone has a shorter duration of action than most opioids; neonates redosed as needed
   f. Specific opioid drugs
      (1) Meperidine
         (a) Immediately transferred to the fetal circulation
         (b) Minimal fetal depression if birth is within the first hour of drug administration
      (2) Morphine
         (a) Causes observable clinical CNS depression in the newborn
         (b) Has a direct vasoconstrictor effect on placental vessels
      (3) Oxymorphone, hydromorphone
         (a) Better analgesia and sedation than meperidine or morphine
         (b) Produce neonatal depression
      (4) Fentanyl
         (a) Potent analgesic
         (b) Short duration respiratory depression

IV. Injectable anesthetic drugs

A. Dissociogenic drugs (ketamine, tiletamine)
   1. Produce immobilization and analgesia

2. Poor muscle relaxation
3. Rapidly cross the placenta, producing fetal depression within 5 to 10 minutes of drug administration
4. Dissociogenic drugs
   a. Ketamine
      (1) Good restraint in female cats with minimal fetal depression when used intravenously (IV) or intramuscularly (IM) in low doses (2 mg/kg of body weight IV; 10 mg/kg IM)
      (2) Poor muscle relaxation
      (3) May increase uterine tone and decrease uterine blood flow, leading to fetal hypoxia
      (4) Fetal blood levels reach 70% of those in the mother
      (5) Minimal clinical CNS depression is evident in the neonate
   b. Telazol (tiletamine-zolazepam)
      (1) Similar to ketamine but produces better muscle relaxation
      (2) Greater respiratory depression
      (3) Longer duration of effect

B. Propofol
   1. Administered for induction to anesthesia in parturients
      a. Single bolus (2 to 5 mg/kg IV) followed by inhalant anesthetic
   2. Rapidly crosses the placenta readily but short-duration effect on the fetus
      a. Large volume of distribution results in a rapid fall in plasma concentrations
   3. Fetal respiratory depression

C. Alphaxalone
   1. Administered for anesthetic induction
   2. Single bolus (2 mg/kg, IV); puppy viability the same as propofol
   3. Similar respiratory depression to propofol

D. Barbiturates
   1. Readily crosses the placenta into the fetal circulation
   2. Pentobarbital should be avoided because of prolonged fetal CNS depression and reduced fetal ability to metabolize drugs
      a. A dose of barbiturate that does not produce anesthesia in the mother can completely inhibit fetal respiratory movements

3. Ultrashort-acting barbiturates (thiopental)
   a. Thiobarbiturates cross the placenta readily
   b. A single dose of 3 to 6 mg/kg at induction produces only modest placental transfer and does not endanger the normal fetus
      (1) Because of a dependence on redistribution for their duration of action, the use of a single small dose of an ultrashort-acting barbiturate has not been associated with a significant degree of fetal CNS depression
      (2) Redosing is discouraged

V. Peripheral neuromuscular blocking drugs (NMBDs): succinylcholine, pancuronium, atracurium, and vecuronium (see Chapter 10)
   A. Are highly ionized and have a high molecular weight, resulting in minimal placental transfer
   B. No analgesia; used only in combination with analgesic drugs
   C. No demonstrable effect on the newborn
   D. Succinylcholine metabolism is reduced and effect prolonged because of a decrease in pseudocholinesterase

VI. Inhalant anesthetic drugs (isoflurane, sevoflurane)
   A. All inhalant anesthetics readily cross the placenta because of their low molecular weight and high lipid solubility
   B. The degree of fetal CNS depression depends on the depth and duration of maternal anesthesia
   C. Specific inhalant drugs
      1. Nitrous oxide
         a. Rapidly crosses the placenta
         b. Administration exceeding 15 minutes results in fetal CNS depression
         c. Hypoxia and diffusion hypoxia in the fetus, can be minimized by oxygen administration
      2. Isoflurane
         a. Quickly appears in the fetal circulation
         b. Rapid and potent uterine relaxant
         c. Surgery should be performed as quickly as possible if administered for cesarean section
            (1) The degree of fetal CNS depression does not correlate with maternal blood inhalant concentration
            (2) Neonatal respiratory depression may be severe, requiring manual ventilation

d. Rapid elimination with ventilation may be an advantage compared with injectable techniques

3. Desflurane's rapid onset and elimination minimize the duration of maternal and fetal CNS depression

Anesthetic Techniques

I. General principles

A. The anesthetic technique should be based on familiarity with the technique and drugs, as well as avoidance of excessive fetal CNS and cardiorespiratory depression

B. Intubation is recommended

C. Local and regional analgesic techniques facilitate surgery

D. Presurgical preparation and oxygenation should be completed before the anesthetic drugs are administered. Prep animal in lateral recumbency if possible.

E. Sedatives, tranquilizers, and other drugs that can be antagonized are preferred over excessive physical force and subsequent maternal-fetal distress

F. Limit time in dorsal recumbency to a minimum because of pressure on the diaphragm

II. Anesthetic techniques by species (Table 27-1)

III. Analgesia (Tables 27-2 and 27-3)

TABLE 27-1 Anesthetic Techniques By Species

Species	Drug/technique	Dosage	Comment
DOG, CAT			
Local Anesthetic Techniques			
Dog, cat	Epidural with 2% lidocaine	0.3 mL/kg body weight lidocaine	Requires assistant for physical restraint; use sedative/tranquilizer in all but extremely tractable animals
	Line block with 2% lidocaine	Up to 5 mg/kg dogs 2.0 mg/kg cats	Often combined with general anesthetic technique
General Techniques (Tractable Animals)			
	Propofol	4.0-6.0 mg/kg IV	Dose is reduced if preceded by sedative/tranquilizer
	Diazepam or midazolam-ketamine induction	0.25 mg/kg diazepam plus 5 mg/kg ketamine IV	Single-bolus dose depresses fetus minimally

Continued

TABLE 27-1 Anesthetic Techniques By Species—cont'd

Species	Drug/technique	Dosage	Comment
			Diazepam-ketamine good in animals that are depressed and in shock
	Telazol induction	0.5-2.0 mg/kg IV	Single administration causes minimal fetal CNS depression; prolonged maternal recovery
	Alphaxalone	1.5-2.0 mg/kg IV	Dose will be reduced if preceded by sedative/tranquilizer
Maintenance			
	Isoflurane; sevoflurane; desflurane	See Chapters 9, 10, and 11	Administer inhalant agent as late into procedure as possible
Intractable Animal			
	1. Premedication Dogs: acepromazine-oxymorphone; methadone; hydromorphone	0.05 mg/kg, Ace, IM plus opioid	Use prior to induction and maintenance techniques described for tractable animals
HORSE			
	Premedication: acepromazine, xylazine; detomidine; romifidine	Acepromazine: 0.02-0.04 mg/kg IV	Adjust dosage for physical condition of the mare; guaifenesin or diazepam to produce relaxation and reduce the dose of ketamine
		Xylazine: 0.2-0.7 mg/kg IV Detomidine: 10-20 μg/kg Romifidine: 80-160 μg/kg	
	Induction: guaifenesin and ketamine	Guaifenesin: 50-100 mg/kg; ketamine 1.5-2.0 mg/kg	
	Maintenance: sevoflurane; isoflurane		

TABLE 27-1 Anesthetic Techniques By Species—cont'd

Species	Drug/technique	Dosage	Comment
Local Techniques			
COW			
	Standing paravertebral analgesia; line block; inverted L block	2% lidocaine (see Chapter 5 for techniques)	Suitable for tractable animals and animals in good physical condition
	Anterior epidural	2% lidocaine, 0.2 mL/kg at Co_1-Co_2 junction	Induces recumbency with motor and sensory block of caudal abdomen anterior to the umbilicus; monitor arterial blood pressure
General Techniques			
	Guaifenesin-ketamine-xylazine	500 mg ketamine 25 mg xylazine 500 mL of 5% guaifenesin + 0.5-1.0 mg/kg until effective for maintenance	
SHEEP, GOAT			
	Guaifenesin-ketamine	500 mL 5% guaifenesin containing 500 mg ketamine 0.5-2.0 mg/kg induction maintenance until effective	Intubate; copious salivation; moderate to poor muscle relaxation Add 25 mg xylazine to mixture, but fetal CNS depression is greater
	Guaifenesin-ketamine induction; sevoflurane, isoflurane	50 mg/kg guaifenesin	Guaifenesin allows small bolus doses of ketamine 2 mg/kg
	Diazepam-ketamine	1 mL diazepam plus 1 mL ketamine: 1 mL/15 kg	
	Mask induction isoflurane or sevoflurane	Until effective	Useful in sick, toxic animals and when fetal viability is not a concern

Continued

TABLE 27-1 Anesthetic Techniques By Species—cont'd

Species	Drug/technique	Dosage	Comment
Maintenance			
	Isoflurane or sevoflurane		
PIG			
	Epidural/Spinal	2% lidocaine (see Chapter 5 for technique)	Restraint of sow's head and front legs necessary
	Injectable techniques	See Chapter 26	

CNS, Central nervous system; *IM*, intramuscularly; *IV*, intravenously.

TABLE 27-2 Analgesic Doses for Pregnant Dogs and Cats

Opioid	Dose (mg/kg)	Route of Administration	Dosing Interval (hr)
Morphine	**Dog**		
	0.5-1.0	SQ, IM	4-6
	0.1-0.3	Epidural	Once
	Cat		
	0.1-0.2	SQ, IM	4-6
Hydromorphone	**Dog**		
	0.04-0.2	IM, IV	4-6
	Cat		
	0.02-0.10	SQ, IM, IV	4-6
Methadone	**Dog and cat**		
	0.1-0.5	SQ, IM, IV	4-6
Buprenorphine	0.005-0.02	SQ, IM, IV, PO	6-8

IM, Intramuscularly; *IV*, intravenously; *PO*, orally; *SQ*, subcutaneously.

TABLE 27-3 Analgesic Doses for Bitches and Queens

Opioid Agonists (narcotics)	Dose (mg/kg)	Route of Administration	Interval (hr)
Morphine	**Dog**		
	0.1-0.5	IV/hr	CRI
	0.5-1.0	SQ, IM	1-4
	0.1-0.3	Epidural	8-12
	0.5-2.0	PO titrate until effective	4-6
	Cat		
	0.1-0.2	SQ, IM	
	0.5-1.0	PO titrate until effective	8-12
Hydromorphone	**Dog**		
	0.04-0.20	IV	4-6
	0.05-0.20	SQ, IM	4-6
	Cat		
	0.04-0.10	IV	4-6
	0.05-0.10	IM, SQ	4-6
Methadone	**Dog and cat**		
	0.1-0.5	SQ, IM, IV	2-4
Fentanyl	**Dog and cat**		
	1-5+ μg/kg	IV loading	0.5-1.0
	1-5 μg/kg	IV/20-60 min	CRI
	50 μg/kg for anesthesia	IV 60 min	CRI
Codeine	**Dog**		
	1-2	PO titrate until effective	6-8
	Cat		
	0.5-1.0	PO titrate until effective	12

CRI, Constant rate infusion; *IM*, intramuscularly; *IV*, intravenously; *PO*, by mouth; *SQ*, subcutaneously.

28 Respiratory Emergencies

"Each person is born to one possession which out values all his others—his last breath."
MARK TWAIN

OVERVIEW

Respiratory depression occurs during every anesthetic episode. Central nervous system (CNS) depression can lead to hypoventilation (increased $PaCO_2$), hypoxemia (decreased PaO_2), and apnea. Hypoventilation cannot always be determined by visual inspection of chest wall movements but can be assessed by arterial blood gas analysis or capnography. Although potentially devastating, respiratory depression, if recognized early, is easily treated by establishing a patent airway and providing adequate inflation of the lungs to ensure appropriate gas exchange.

I. Patterns of respiration
- A. **Eupnea:** normal rate and rhythm
- B. **Tachypnea:** increased respiratory rate; caused by fever, hypoxia, hypercapnea, pneumonia, or lesions of the CNS respiratory centers
- C. **Bradypnea:** slow but regular respirations; caused by sleep, anesthesia, opioids, hypothermia, neoplasia, or respiratory decompensation
- D. **Apnea:** absence of respiration; may be periodic; caused by drug depression, muscle paralysis, overventilation, obstruction, shock, increased intracranial pressure, or surgical manipulation of vagus and splanchnic nerves
- E. **Hyperpnea:** large respirations (increased tidal volume); rate normal; caused by excitement, pain, surgical stimulation, hypoxia, hypercarbia, heat, or cold
- F. **Cheyne-Stokes respiration:** respirations become faster and larger, then slower, followed by an apneic pause; caused by increased intracranial pressure from head trauma or neoplasia, meningitis, renal failure, severe hypoxia, anesthetic drug overdose, or high altitude
- G. **Biot's respiration:** respirations that are faster and deeper than normal, with abrupt pauses between them; each breath has

approximately the same tidal volume; caused by anesthesia in normal, athletic horses and greyhounds; spinal meningitis; or drugs that cause generalized CNS depression

H. **Kussmaul's respiration:** regular and deep respirations without pauses; animal's breathing usually sounds labored, with breaths that resemble sighs; caused by renal failure, metabolic acidosis, or diabetic ketoacidosis

I. **Apneustic:** prolonged gasping inspiration, followed by extremely short, inefficient expirations; caused by high doses of drugs (e.g., ketamine in cats and horses or excessive doses of guaifenesin in horses) or lesions in the pons and thalamus

General Considerations

I. Definition: a respiratory emergency is the inability to maintain adequate gas exchange (oxygen [O_2]; carbon dioxide [CO_2]) such that tissue oxygenation and acid-base status become compromised

II. Clinical causes

A. Potential causes of impaired gas exchange:

1. Hypoventilation caused by preanesthetic or anesthetic drugs
2. Improper placement (e.g., esophageal) of the endotracheal tube
3. Parenchymal pulmonary disease and pulmonary edema (diffusion impairment)
4. Pleural cavity disease (pneumothorax, fractured ribs)
5. Airway obstruction
   a. Foreign body or material in trachea
      (1) Rubber ball
      (2) Bone
      (3) Toy
      (4) Vomitus
   b. Laryngeal disease
      (1) Laryngeal paralysis
      (2) Laryngeal spasm with intubation
   c. Small or obstructed endotracheal tubes. Do not overinflate the cuff.
   d. Restricted chest wall movement; improper physical restraint or positioning for surgery, improper bandaging
   e. Nasal obstruction or edema (brachiocephalic breeds)
   f. Displacement of the soft palate

6. Low inspired oxygen (FiO_2)
   a. O_2 flow turned off on anesthetic machine
   b. Delivery of nitrous oxide (N_2O) in excess of 70%
7. Closed pressure release ("pop-off") valve
   a. Increased anesthetic circuit pressure impairs or prevents exhalation. Increases in airway pressure may result in increases in intrathoracic pressure, limiting venous return and cardiac output and resulting in cardiovascular collapse. Pneumothorax may occur due to rupture of the airway.

III. Species, age, size, and concurrent lung pathology determine respiratory frequency, rate of lung inflation, inflation pressure, and tidal volume to be delivered; larger animals generally require slower inflation rates, lower frequencies of breathing, and larger volumes. Note: Three to 4 minutes of preoxygenation with 100% O_2 can markedly prolong the time to hemoglobin desaturation, hypoxemia, and cyanosis.

A. Pneumothorax should be corrected immediately to ensure adequate lung expansion and reduce the potential for developing tension pneumothorax
   1. "A little pneumothorax" is never a good thing

B. Intrathoracic air or fluid should be removed

IV. Treating hypoventilation and apnea

A. If the animal is taking small-volume breaths or is apneic, establish an airway and institute artificial ventilation with room air or O_2; O_2 is preferred
   1. Deliver O_2 to endotracheal or tracheotomy tube
   2. Intubate nasally and administer O_2
   3. Face mask and O_2
   4. Mouth-to-nose
   5. Mouth-to-mouth

B. Control breathing rate if apneic; assist ventilation if breathing
   1. Rate: 6 to 15 breaths/min
   2. Inspiratory time: 1 to 3 seconds, depending on size of the animal
   3. Maintain proper inspiratory time /expiratory time ratio of 1:2, 1:3, or 1:4
   4. Inflate lungs to 15 to 20 cm H_2O if chest is closed (up to 20 to 30 cm H_2O in large animals). Note: Higher pressures may be required in animals that have fluid or masses in the chest or that have restrictive lung disease.

5. Inflate lungs to 20 to 30 cm H_2O if chest is open or atelectasis of lungs has occurred (up to 40 cm H_2O in large animals)
6. Tidal volume (volume of air inspired or expired in a single normal breath)
   a. Approximately 10 to 15 mL/kg of body weight

Principal Points

- Preoxygenate before induction to anesthesia
- Establish a patent airway!
- Administer 100% O_2

V. Assist or control ventilation until the animal can maintain adequate tidal breathing and gas (O_2; CO_2) exchange, normal mucous membrane color, and hemoglobin saturation (SpO_2; see monitoring)
   A. Know how to use a ventilator (see Chapter 13)

Clinical Signs of Respiratory Distress

I. Slow or rapid small volume breaths, apnea or dyspnea
II. Increased frequency of breathing; respiratory rate and effort are generally increased in animals with respiratory distress or disease
III. Coughing, stridor, or sonorous breathing sounds are associated with airway obstruction. Animals may vomit.
IV. Cyanosis: bluish discoloration of the mucous membranes
   A. Cyanosis may be absent in severely anemic animals (hemoglobin less than 5 g/dL); animals may become pale gray
V. Abnormal postures
   A. Open-mouth breathing
   B. Extension of the head and neck
   C. Abduction of the forelimbs

Treating Respiratory Distress

I. Treat the cause and administer O_2
II. Control or assist breathing when necessary
   A. Ambu-Bag
   B. Use a volume-cycled ventilator with a standing bellows (see Chapter 13)
III. Use respiratory stimulants when necessary

A. Doxapram: 1 to 4 mg/kg intravenously (IV); repeat if necessary; or 5 to 10 μg/kg/min IV infusion
B. Antagonize respiratory depressant drugs if indicated

Airway Obstruction

I. Partial airway obstruction may be associated with respiratory disease or obstruction/kinking of the endotracheal tube
II. Conditions that predispose animals to airway obstruction
A. Stenotic nares
B. Edema of the nasal turbinates
C. Elongated or displaced soft palate
1. Brachycephalic breeds
2. Beagles and cocker spaniels
3. Horses
D. Collapsing arytenoid cartilages
1. Congenital in Bouvier des Flandres, bull terriers, and Siberian huskies
2. Acquired in giant-breed dogs (e.g., Saint Bernards)
E. Everting laryngeal ventricles
1. Brachycephalic breeds
2. English bulldogs
3. May be associated with hypothyroidism
F. Collapsing trachea
1. Middle-aged to older, obese, toy-breed dogs, especially miniature poodles, Yorkshire terriers, and Chihuahuas
2. Calves
G. Laryngeal paresis or paralysis ("Lar-Par")
1. Horses
a. Naturally occurring
b. Postsurgical paralysis
2. Congenital, especially in Bouvier des Flandres, bull terriers, and Siberian huskies
3. Acquired in giant-breed dogs, especially in Labrador and golden retrievers
H. Hypoplasia of the trachea
1. Congenital in brachycephalic breeds
III. Other causes of airway obstruction
A. Foreign bodies
B. Nasal disease (e.g., tumor, fungus, parasites)
C. Mucus or blood in airway or endotracheal tube
D. Orotracheal device or anesthetic circuit obstruction due to improper setup or kinking

E. Clinical signs
   1. Noisy, stridorous, or labored breathing (snoring)
      a. Loudest at larynx and pharynx during upper airway obstruction
      b. Low-pitched honking sound during tracheal collapse
   2. Choking, retching, and vomiting
   3. Pawing or clawing at face and throat
   4. Abnormal body positions

IV. Treatment of airway obstruction
   A. Establish patent airway and administer O_2
      1. Intubate
      2. Remove oral, nasal, or tracheal foreign material or blood using forceps, suction, and postural drainage
      3. Perform nasotracheal intubation or tracheotomy, if necessary, to relieve or bypass obstruction (Fig. 28-1)

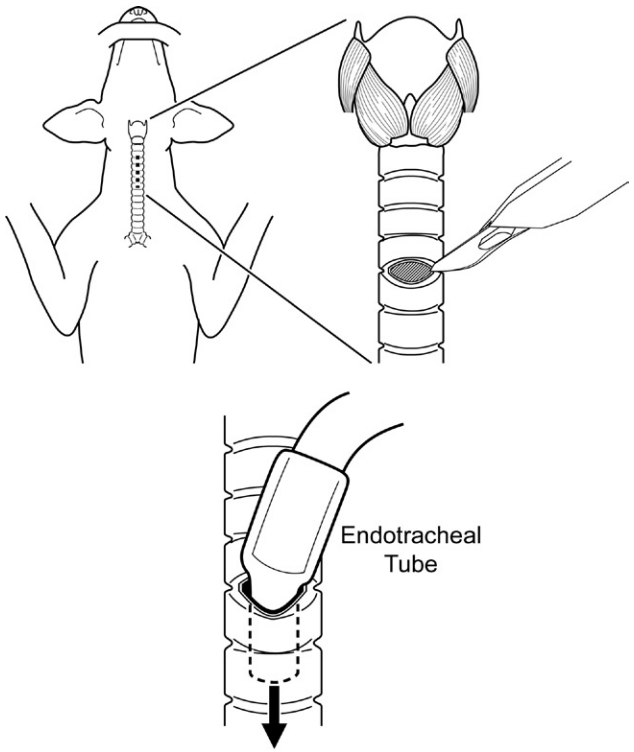


FIG. 28-1. A tracheotomy is easily performed in most dogs and cats.

4. Apply local anesthetic creams (lidocaine) to prevent laryngospasm

B. Relieve pain

C. Supportive care
1. Oxygen cage
2. Intravenous fluid therapy
3. Bronchodilators (albuterol, clenbuterol)
4. Respiratory stimulants, if necessary
5. Sedation; analgesia
6. Antibiotics
7. Corticosteroids
8. Maintain normal body temperature

D. Treat coexisting problems; prepare for surgery
1. Remove foreign bodies or tumors
2. Repair fractures and wounds of the respiratory system
3. Drain fluid or air from the thorax

E. Care of tracheotomy tube
1. Apply suction every 2 hours using aseptic technique
2. Nebulize with saline solution or acetylcysteine diluted with saline solution to prevent airway drying
3. Maintain normal hydration
4. Monitor body temperature

Respiratory Diseases

I. Classification

A. Life-threatening
1. Acute, fulminating bronchopneumonia
2. Smoke inhalation
3. Aspiration pneumonia

B. Trauma: pulmonary contusion

C. Pulmonary edema

D. Pulmonary embolism

II. Diagnosis

A. Increased respiratory rate, cyanosis, dyspnea, depression

B. Radiographs of the chest

C. Laboratory tests
1. Complete blood count
2. Transtracheal aspirate, bronchoalveolar lavage
3. Bronchoscopy
4. Blood gas determination
5. PO_2, $PaCO_2$, end-tidal CO_2

III. Treatment

A. Remove aspirated material
B. Maintain the patency and function of the airways
C. Supply O_2
D. Treat infection
E. Supportive care
   1. Administer O_2 (>40% or more) using the following methods:
      a. Face mask
      b. Nasal catheter
      c. Pediatric incubator
      d. Oxygen cage
      e. Tracheotomy and positive-pressure ventilation (if laryngeal spasm or airway obstruction persist)
   2. Humidify the air by nebulization with normal saline solution to improve secretion removal
   3. Maintain normal body hydration with fluids IV or subcutaneously (SQ) to prevent drying and thickening of secretions
   4. Perform periodic coupage (percussion of the chest)
   5. Provide physiotherapy with deep breathing; this aids in removal of secretions, increases lymphatic drainage of the lungs, and activates surfactant
   6. Bronchodilators are helpful in reversing bronchial spasm and constriction (e.g., aminophylline, clenbuterol)
   7. Anticoagulants and O_2 in animals with pulmonary embolism
   8. Analgesics may be used for pain and apprehension in selected animals
      a. Monitor blood gases to detect respiratory depression
   9. Medical therapy of pulmonary edema
      a. Confine the animal to a cage to decrease the workload of its heart; administer O_2, sedation (low-dose opioids), and diuretics (furosemide) when indicated
      b. Improve ventilation by endotracheal suctioning
      c. Nebulize with 40% alcohol
      d. Carefully monitor IV fluid administration

Chest Cavity Diseases

I. Definition: Chest cavity disease includes problems that decrease the functional capacity of the lungs because of fluid, masses, or inflammation in the thoracic cavity or damage to the integrity of the thoracic wall

II. Common chest cavity diseases
- A. Pneumothorax
  1. Open (wound)
  2. Closed (usually after trauma)
  3. Spontaneous (unknown origin)
  4. Tension (lungs deflated, pressure on great vessels)
- B. Pleural effusion
  1. Chylothorax
  2. Pyothorax
  3. Hydrothorax
  4. Hemothorax
  5. Neoplastic effusion
  6. Infectious, inflammatory effusion
- C. Diaphragmatic hernia (congenital or traumatic)
- D. Trauma: flail chest (free rib segment)

III. Causes
- A. Pneumothorax: accumulation of free air in the pleural cavity
  1. Trauma, resulting in pleural or parenchymal lacerations or tracheobronchial ruptures, is the most common cause of pneumothorax
  2. Pneumothorax can occur spontaneously in Afghan hounds (Fig. 28-2, *A*)
  3. Tension pneumothorax: air accumulates in pleural space during inspiration and is not expelled during expiration; intrapleural pressure increases, collapsing the lungs and great vessels (Fig. 28-2, *B*)
  4. Other causes
     a. Penetrating injuries from bite wounds and projectiles
     b. Rupture of congenital bullous emphysematous or granulomatous lung lesions (blebs or bullae)
     c. Rupture of parasitic cysts (*Paragonimus*); neoplasia
     d. Pleuritis
     e. Iatrogenic causes
        (1) Overzealous intermittent positive-pressure ventilation (particularly in cats); can result in pulmonary barotrauma, pneumomediastinum, and subcutaneous emphysema
        (2) Intrathoracic surgical procedures
- B. Pleural effusion: abnormal fluid accumulation within the pleural cavity
  1. Hemothorax

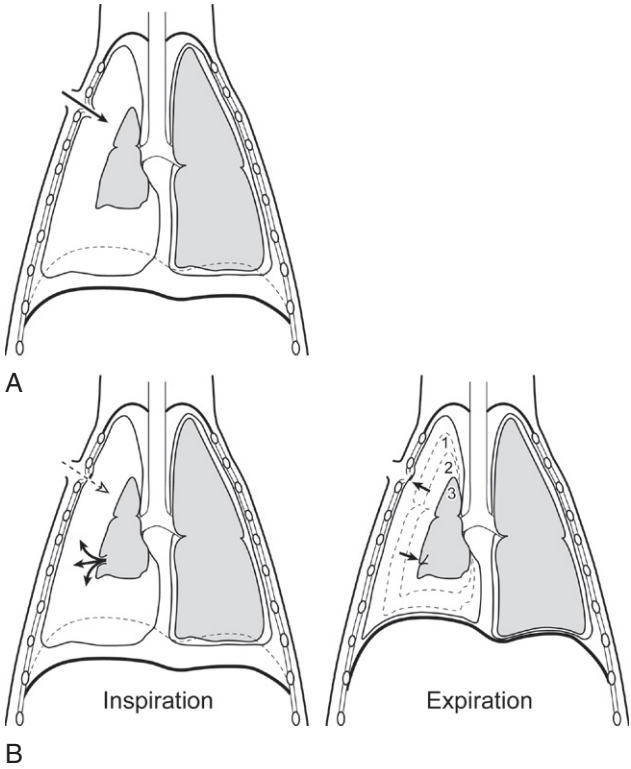


FIG. 28-2. A, Open pneumothorax. Air moves into the chest. The lung collapses as a result of loss of negative pressure. **B,** Tension pneumothorax. During inspiration, air moves one way into the chest, gradually increasing the intrathoracic volume of air and collapsing the lung. As pressure increases, great vessels collapse and venous return is reduced. Note: Because the mediastinum is incomplete in most species, air usually is found throughout the thoracic cavity.

   a. Rupture of cardiac and intrathoracic blood vessels from trauma
   b. Clotting disorders
   c. Bleeding neoplasms (e.g., hemangiosarcoma)
   d. Lung-lobe torsion
   e. Pleuritis
2. Chylothorax
   a. Accumulation of lymphatic fluid in the pleural space
      (1) Rupture of the thoracic duct
      (2) Idiopathic lymphatic obstruction
3. Hydrothorax

a. Hypoproteinemia
b. Heart failure and cardiomyopathy

4. Pyothorax (pleuritis)
a. Penetrating wounds of the thorax or esophagus
b. Migrating foreign bodies
c. Spread of pulmonary infection and pleuritis
d. Organisms: *Escherichia coli*, *Staphylococcus*, Group B *Streptococcus*, *Pasteurella*, *Nocardia*

C. Chest wall abnormalities
1. Diaphragmatic hernias displace the lungs with abdominal viscera
2. Flail chest caused by proximal and distal fractures of several consecutive ribs
a. Chest wall is drawn inward with expiration and blown outward with inspiration (paradoxic movement [Fig. 28-2, *B*])
b. Lung contusion and hemopneumothorax may be present, precipitating acute respiratory distress

IV. Diagnosis
A. Auscultation and percussion
B. Thoracic radiography
C. Computed tomography
D. Ultrasound examination
E. Thoracocentesis

V. Treatment
A. Establish a patent airway
B. Administer O_2
C. Remove the cause
1. Needle aspiration (air or liquid)
2. Tube thoracostomy (Fig. 28-3)
a. Indications
(1) Acute severe pneumothorax
(2) Tension pneumothorax
(3) Pneumothorax associated with rib fractures, emphysema, or hemothorax
(4) Fluid accumulation
(5) Situations where repeated needle evacuations are necessary
b. Methods of drainage
(1) Intermittent aspiration using a syringe and three-way stopcock
(2) Unidirectional flutter (Heimlich) valve (Fig. 28-4)

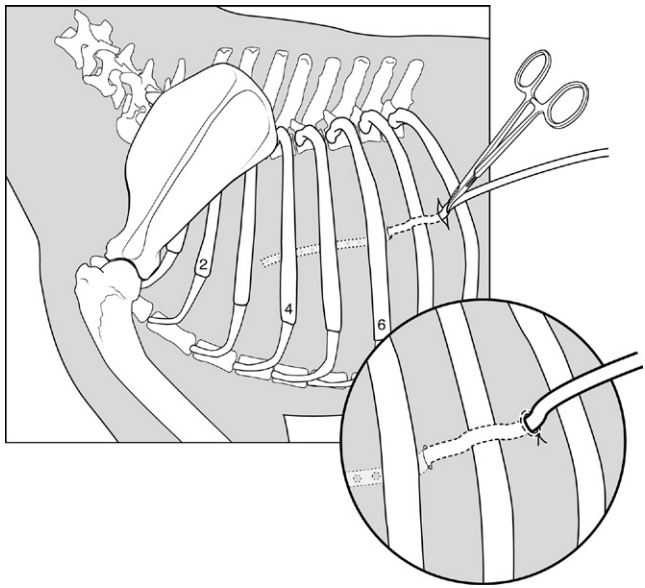


FIG. 28-3. A chest tube is placed to restore negative intrathoracic pressure by connecting it to a Heimlich valve (Fig. 28-4) or a three-bottle negative pressure system (Fig. 28-5).

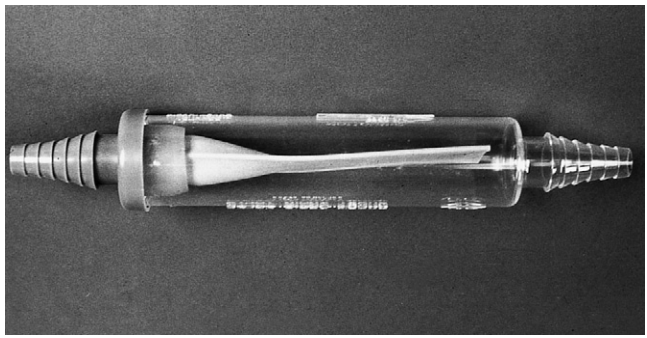


FIG. 28-4. A one-way (Heimlich) valve is placed at the end of the chest tube to evacuate air from the chest.

(3) Connecting the chest tube to a suction pump (10 to 15 cm H_2O negative pressure)
(4) Connecting the chest tube to underwater seal units (Fig. 28-5). Thoracic drainage units are commercially available.

3. Complications
   a. Accumulation of fibrin and blood

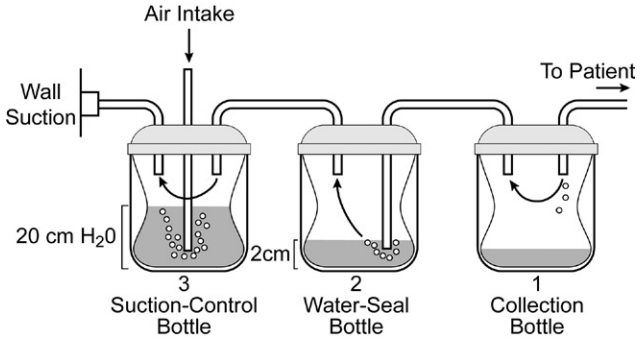


FIG. 28-5. An underwater seal system (three-bottle) for connecting to a chest tube and creating negative intrathoracic pressure. All connections must be airtight.

b. Displacement of tube
c. Kinking of tube
d. Subcutaneous emphysema
e. Lung tissue entrapment and infarction after vigorous suction
f. Infection
g. Pain

Iatrogenic Causes of Respiratory Emergencies

I. Inadequate animal evaluation
II. Poor anesthetic techniques
A. Anesthetic overdose (e.g., propofol)
B. Excessive dead space in anesthetic equipment, incompetent nonrebreathing valves
C. Lack of O_2 delivery
1. N_2O on; O_2 off
2. Excessive use of N_2O (more than 70%)
3. O_2 supply depleted
4. Anesthetic system not connected properly
5. Endotracheal tube too small
6. Endotracheal tube cuff overdistended
a. Tracheal tube collapsed within cuff
b. Postsurgical stenosis of trachea
7. Inappropriately placed endotracheal tube
a. In esophagus
b. In pharynx
c. At or caudal to bifurcation of trachea

D. Kinked or obstructed anesthetic delivery hoses and tubes
E. Lungs overdistended during mechanical ventilation
F. Neuromuscular paralysis of diaphragm and intercostal muscles without ventilatory support

III. Restrictive bandages around the chest
IV. Inadequate monitoring of the animal

Other Causes of Pulmonary Insufficiency

I. Ventilation-perfusion inequalities
A. Decreased cardiac output
B. Atelectasis
1. Absorption: absorption of O_2 from behind blocked small airways
2. Compression: compression of lungs by distended abdominal viscera pressing against the diaphragm (colic in horses; rumen in cattle, sheep, and goats; bloat in dogs)
3. Gravitational effects

II. Increased venous admixture (shunts)
A. Pulmonary arteriovenous shunts
B. Bronchial vessel shunts
C. Atelectasis (physiologic shunt)
D. Pulmonary neoplasia
E. Congenital cardiac disease (tetralogy of Fallot)

Respiratory Arrest

I. Cessation of breathing from any of the previously discussed causes

II. Treatment
A. Establish a patent airway
1. Remove the obstruction or foreign material
2. Intubate
3. Consider a tracheostomy if unable to orotracheally intubate (see Fig. 28-1)

B. Provide manual or mechanical ventilation
1. Room air delivered through Ambu-Bag (Fig. 28-6)
2. 100% O_2 delivered through anesthetic system
3. Transtracheal insufflation of O_2; 3 to 6 L/min in dogs

C. Proceed with cardiopulmonary resuscitation, if necessary (see Chapter 29)
D. Acupuncture resuscitative techniques have been used successfully in emergency situations
1. Use 25- to 28-gauge hypodermic needle, 25 to 50 mm long

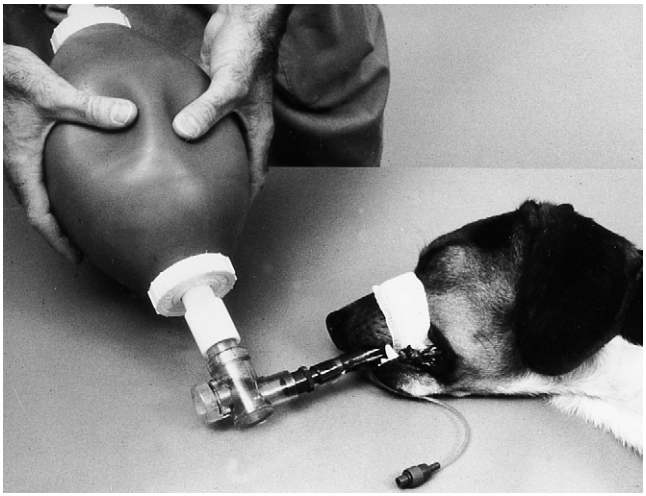


FIG. 28-6. Ventilation with an Ambu-Bag. Ambu-Bags are self-inflating.

2. Insert the needle 10 to 20 mm into the nasal septum at point GV 26, along the midline of the nasolabial cleft at the left of the lower canthi of the nostril
3. Twirl the needle strongly and move it up and down
4. Use this technique as an adjunct to, but not a replacement for conventional techniques

Preventing Respiratory Emergencies

I. Proper preanesthetic evaluation and diagnostic evaluation (ultrasound, radiography)
  A. Physical examination
  B. Auscultation
  C. Radiography
  D. Blood gas analysis
II. Use of proper anesthetic and monitoring equipment (see Chapter 14)
III. Adequate inspection of anesthetic equipment
IV. Preoxygenate: administer O_2 for 3 to 5 minutes before induction of anesthesia
V. Proper drug and dose selection of preanesthetic and anesthetic drugs
VI. Careful and continuous monitoring
VII. Awareness of possible problems

Using Respiratory Stimulants, Bicarbonate, and Bronchodilator Drugs

I. Doxapram (1 to 4 mg/kg IV in small animals, 0.2 to 0.6 mg/kg IV in large animals) is a general CNS and respiratory center stimulant and can be administered by infusion (5 to 10 μg/kg/min) until effective; a centrally acting respiratory stimulant; increases tidal volume and, in larger doses, respiratory rate; causes small elevations in arterial blood pressure and heart rate and may cause arousal from anesthetic depression; increases cerebral metabolic rate. Use is controversial.

II. Sodium bicarbonate (1 to 2 mEq/kg IV); used to correct metabolic (nonrespiratory) acidosis, which may occur during hypoxia, or complete respiratory and cardiac arrest; excessive administration may produce hypokalemic metabolic alkalosis or paradoxic cerebrospinal fluid acidosis. Use is controversial: administer when blood pH and HCO_3^- values are not available and metabolic acidosis is suspected.

III. Aminophylline: up to 4 mg/kg IV slowly over 30 minutes, 2 to 4 mg/kg intramuscularly (IM); dilates bronchial smooth muscle and may be useful in asthma and bronchospasm; has inotropic action on the heart

IV. Specific antagonists (see Chapter 3)

A. Narcotic antagonists (naloxone, nalorphine, levallorphan); act by competitively displacing narcotic analgesics from opiate and nonopiate receptors

B. Neostigmine, edrophonium: reversal of nondepolarizing neuromuscular blocking drugs (see Chapter 10)

C. a_2-Antagonists (yohimbine, tolazoline, atipamezole (see Chapter 3)

D. Benzodiazipine antagonists (flumazenil)

Treating Pulmonary Edema

I. Measures to improve ventilation-gas exchange

A. Oxygen (FiO_2 40% to 50%)

B. Reduction of activity (cage rest) to decrease O_2 demand

C. Sedation, relief of anxiety

1. Morphine (dogs) 0.2 to 0.5 mg/kg SQ, IM, IV
2. Acepromazine 0.1 to 0.2 mg/kg SQ, IM (maximum of 4 mg)
3. Low dosages of an α_2-agonist (e.g., dexmedetomidine; detomidine) administered IM

D. Endotracheal suctioning in severe cases to clear foam from airways

E. Ethyl alcohol nebulization (40%) into O_2 (prevents foaming in airways)
F. Positive-pressure ventilation
   1. Manual or mechanical
      a. Criteria for ventilation: PaO_2 less than 60 mm Hg, $PaCO_2$ more than 50 to 60 mm Hg, persistent cyanosis, dyspnea, or tachypnea (all while breathing 60% O_2)
   2. Positive end-expiratory pressure, 5 to 10 cm H_2O, is used to ventilate stiff lungs (e.g., pulmonary edema, pneumonia)

II. Measures to reduce capillary hydrostatic pressure and pulmonary edema
A. Oxygen
B. Decrease circulating blood volume
   1. Diuretics: furosemide 2 to 4 mg/kg IV, IM, SQ, by mouth every 6 to 8 hours
C. Redistribute pulmonary blood flow to other circulatory beds
   1. Morphine: besides sedative effects, increases systemic venous capacitance
   2. Furosemide: besides diuresis, redistributes pulmonary blood flow by increasing systemic venous capacitance
   3. Vasodilators (carefully)
      a. Sodium nitroprusside, nitroglycerine
      b. Peripheral vasodilation redistributes circulation away from pulmonary beds (noncardiogenic) and decreases resistance to left ventricular outflow (afterload; cardiogenic)
D. Improve cardiac function (cardiac output); mostly used in cardiogenic edema
   1. Positive inotropes (dopamine, dobutamine)
   2. Antiarrhythmics (lidocaine) to control arrhythmias, if present

III. Other therapy
A. Corticosteroids (e.g., prednisolone sodium succinate: 20 to 30 mg/kg intravenously)

IV. Monitoring the response to therapy
A. Physical examination (including rate and depth of breathing, auscultation, mucous membrane color)
B. Sequential arterial blood gas analyses (see Chapter 15)
C. Thoracic radiography; ultrasonography
D. Pulse oximetry (SpO_2); capnography (end-tidal CO_2; $ETCO_2$) blood gases (O_2, CO_2)

Cardiovascular Emergencies

29

"It is by presence of mind in untried emergencies that the native metal of a man is tested."
JAMES RUSSELL LOWELL

OVERVIEW

Most drugs used for anesthesia produce hypotension. Hypotension, cardiac arrhythmias (bradycardia, ventricular tachycardia), and decreased peripheral perfusion (low cardiac output) leading to shock can occur after the administration of sedatives and anesthetics. The potential for cardiac emergencies is increased in severely stressed, debilitated, or traumatized animals. A variety of physical and pharmacologic approaches have been developed to prevent or reverse deterioration of the circulation and reestablish normal hemodynamics. It is imperative to have a physical, technical, and working knowledge of the techniques and drugs used to provide successful cardiopulmonary resuscitation (CPR). Successful resuscitation should be followed by continuous intensive nursing care and close monitoring for 3 to 7 days (see acvecc-recover.org).

General Considerations

I. Definition: a cardiovascular emergency is any condition involving the heart or vasculature that results in the inability to maintain adequate blood flow, tissue perfusion, and oxygenation

II. Common causes
- A. Respiratory failure (hypoxia)
  1. Hypoventilation (hypercarbia, increased $PaCO_2$)
  2. Hypoxemia (decreased PaO_2)
  3. Ventilation-perfusion abnormalities
  4. Intracardiac or pulmonary shunt
  5. Diffusion abnormalities
- B. Acid-base imbalance
  1. Respiratory acidosis ($PaCO_2$ >60 mm Hg)
  2. Metabolic acidosis (usually lactic acid)
  3. Respiratory alkalosis ($PaCO_2$ <35 mm Hg)
  4. Mixed metabolic and respiratory alkalosis or acidosis

C. Electrolyte imbalance
   1. Hyperkalemia (bradycardia; poor contractility, vasodilation)
   2. Hypokalemia (tachycardia)
   3. Hypocalcemia (hypocontractility, hypotension)
   4. Hypercalcemia (cardiac arrhythmias)

D. Autonomic imbalance
   1. Increased sympathetic tone; increased myocardial automaticity and irritability
   2. Increased parasympathetic tone; predisposition to bradycardia and various forms of heart block; predisposition to atrial arrhythmias, including atrial fibrillation
   3. Increased sympathetic and parasympathetic tone; predisposition to ventricular arrhythmias

E. Hypothermia (35° C, 95° F; see Chapter 17)

F. Air embolism

G. Rapid, excessive, or inappropriate drug administration
   1. Any hypersensitivity or drug overdose such as a hypotensive crisis caused by rate or amount of drug administered
      a. Most commonly observed after intravenous drug administration
      b. Treatment includes fluids, steroids, and occasionally vasopressors (i.e., epinephrine)
      c. Administration of catecholamines during inhalant anesthesia (ventricular arrhythmias, tachycardia)
   2. Accidental intra-arterial drug administration (e.g., accidental intracarotid administration of preanesthetic drugs [phenothiazines, xylazine] in horses and cattle); treatment should include adequate padding, anticonvulsants (diazepam), fluids, and glucocorticosteroids
   3. Myocardial depressant factors produced by ischemic organs (e.g., pancreas)
   4. Species predisposition: Reports of adverse responses to anesthetic drugs are sometimes reported. The most notable is the postulated association of cardiac arrest after the administration of acepromazine to boxer dogs. The incidence or cause is unknown.

H. Cardiac disease and/or arrhythmias (Table 29-1; Fig. 29-1)

TABLE 29-1 Distinguishing Characteristics of Several Types of Cardiac Failure or Arrest

Cause	Peripheral Pulse	Auscultation of Heart Sounds	Electrocardiogram	Visual observation
Bradycardia	Slow; may be irregular	Slow	Infrequent or irregular QRS complexes	Infrequent coordinated ventricular contractions
Ventricular tachycardia	Rapid; regular or irregular Pulse deficits	Variable intensity; may be muffled	May have wide, bizarre looking QRS complexes; absence of P-QRS relationship	Disorganized, rapidly beating heart
Ventricular fibrillation	None	None	Absence of QRST complexes; fibrillation waves	Fine-to-coarse rippling of the ventricular myocardium
Ventricular asystole	None	None	Absence of QRST complexes; straight-line ECG	No cardiac movement
Pulseless electrical activity	Very weak pulse	Very faint or inaudible heart sounds	Normal PQRST complexes (systolic arterial blood pressure <50 mm Hg)	Feeble or absent cardiac contractions

ECG, Electrocardiogram.

1. Cardiovascular collapse: cardiac failure that is unresponsive to therapy
   a. Occurs primarily in animals that have advanced heart disease or are inadvertently administered too much drug too quickly
2. Bradycardia: lower-than-acceptable heart rate
   a. Increased parasympathetic tone
   b. Hypothermia
   c. Hyperkalemia
   d. Specific medications (opioids, α_2-agonists)
   e. Cardiac disease (e.g., cardiomyopathy, sick sinus syndrome, atrioventricular fibrosis)
   f. Drug overdose

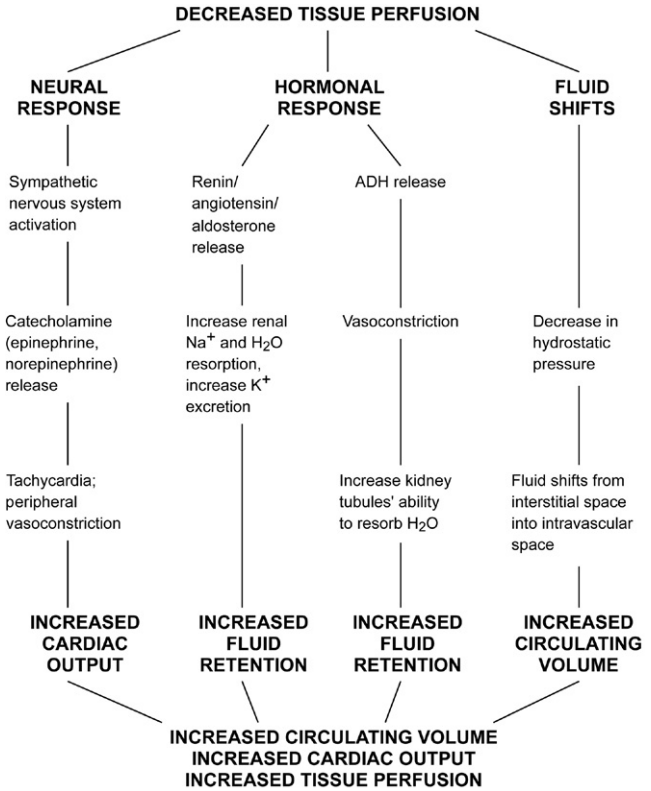


FIG. 29-1. Consequences of decreased tissue perfusion.

3. Tachycardia: higher-than-acceptable heart rate
   a. Increased sympathetic tone
      (1) Inadequate analgesia or anesthesia
      (2) Pain, stress
      (3) Hypotension
      (4) Hypoxia
      (5) Hypokalemia
   b. Specific drug administration (catecholamines, atropine, ketamine)
4. Atrial or ventricular arrhythmias (atrial tachycardia, ventricular tachycardia); associated with conditions that cause ischemia, hypoxia, hypotension, hypercarbia, metabolic acidosis or alkalosis, hyperkalemia,

hypomagnesemia, hypothermia, or hypotension. Cardiac arrhythmias are also caused by surgical manipulation, anesthetic drugs, and cardiac catheterization.

a. Atrial fibrillation
   (1) Variable-intensity heart sounds
   (2) Variable-strength pulses and "dropped" (missing) pulses
   (3) Regularly irregular heart rates
b. Ventricular fibrillation
   (1) Most likely to occur during hypoxia because of the instability of autonomic reflexes and endogenous release of catecholamines
   (2) Rarely associated with the administration of injectable or inhalant anesthetics
   (3) May follow severe hypercarbia, hypoxia, hypovolemia, acidosis, and/or hyperkalemia
c. Ventricular asystole (lack of ventricular contraction)
   (1) Usually associated with anesthetic overdose
   (2) Seen during shock or in toxic animals
d. Pulseless electrical activity; electrocardiogram reading is present, but poor cardiac contraction produces low arterial blood pressure (mean arterial pressure <50 mm Hg). Electromechanical dissociation is a special type of pulseless electrical activity wherein ventricular contraction is uncoupled from electrical activation.
   (1) Hypoxia and ischemia
   (2) Drug overdose

Indicators of Poor Cardiac Function

I. Weak or absent peripheral pulses
   A. Weak cardiac apex beat
II. Irregular pulses or heart sounds
III. Cyanosis: faint blue or gray color in anemic (hemoglobin <5 g/dL) animals
IV. Poor perfusion; prolonged capillary refill time (>2 seconds)
V. Cardiac arrhythmias
VI. Abnormal breathing pattern or apnea (agonal breathing)
VII. Dilated pupils
VIII. Depression, weight loss, or edema
IX. No bleeding from cut surfaces
X. Signs of shock (see Chapter 27)

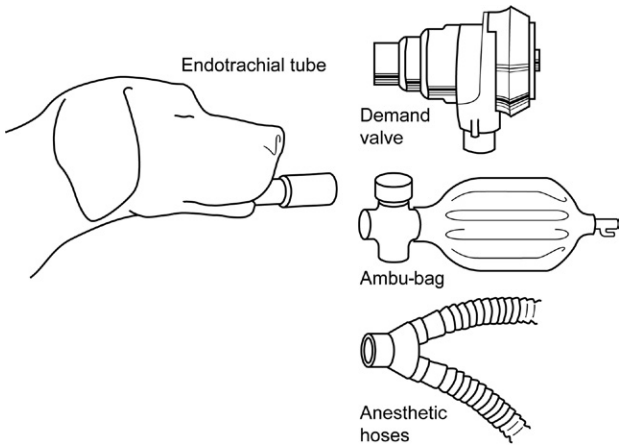


FIG. 29-2. Methods to provide assisted ventilation to an apneic animal.

Equipment Needed for Cardiac Emergencies

I. Equipment should be readily accessible in the event of cardiovascular collapse. TIMING IS CRITICAL.
- A. Cuffed endotracheal tubes and stylet (for small dogs and cats)
  1. Small
  2. Medium
  3. Large
- B. Lighted laryngoscope with small and large blades
- C. Ambu-bag, demand valve, or anesthetic machine (Fig. 29-2)
- D. Tongue depressors
- E. Syringes
  1. Five 1-mL
  2. Five 3-mL
  3. Five 6-mL
  4. Five 12-mL
  5. Five 35-mL
- F. Three-way stopcocks
- G. One roll of 2.5-cm adhesive tape
- H. One roll of 5-cm gauze
- I. One pack of sterile 10 × 10-cm gauze pads
- J. One roll of elastic bandage
- K. Blood administration set
- L. Assortment of appropriately sized needles
- M. Assortment of butterfly needles
- N. Intravenous catheter sets

O. Intravenous fluid administration set and syringe infusion pump
P. Sterile emergency surgery pack
   1. Scalpel handle
   2. Blades: two No.10, two No. 15
   3. Two small hemostats
   4. Thumb forceps
   5. One pair of Metzenbaum scissors
   6. One pair of curved forceps
   7. Several packages of suture
   8. Needle holders
   9. One set of medium-sized rib retractors
Q. Chest tube: Heimlich valve
R. Defibrillator/electrocardiogram
S. Impedance threshold device: increases inspiratory resistance and venous return. Remains to be validated in clinical animals during CPR.

Treatment (Tables 29-2, 29-3; Figs. 29-3, 29-4)

Principal Points (http://acvecc-recover.org)

Immediate chest compression is the key to success
Begin chest compression immediately!

I. Airway (see Chapter 28)
II. Breathing (see Table 29-2)
III. Circulation (Tables 29-3 and 29-4)
IV. Drugs (Table 29-5)
V. Electrocardiogram
VI. Defibrillation (see Table 29-4)

TABLE 29-2 Guidelines for Ventilating Animals

Parameter	Guidelines
Respiratory rate	6-18/min
Tidal volume	12-20 mL/kg
Inspiratory time	<1.5 sec
Inspiratory/expiratory ratio	1:2 to 1:3
Peak inspiratory pressure	15-25 cm H_2O
Positive end-expiratory pressure	3-5 cm H_2O
Sigh (every 5-10 min)	30 cm H_2O
Assessment of ventilatory adequacy	1. Observe chest wall excursions 2. Monitor blood gases; preferred method (maintain $PaCO_2$ at 35-50 mm Hg)

TABLE 29-3 Receptor Activity of Inotropic and Vasoactive Agents

	$Alpha_1$	$Alpha_2$	$Beta_1$	$Beta_2$	Dopaminergic
Isoproterenol	0	0	++++	++++	0
Dobutamine	++/+++	?	++++	++	0
Dopamine	+	+	++++	++	++++
Ephedrine	+	?	++	+	
Epinephrine	++++	++++	++++	+++	0
Norepinephrine	+++	+++	+/++	+/++	0
Phenylephrine	++/+++	+	?	0	0

TABLE 29-4 Treatment for Ventricular Fibrillation

Direct-current Defibrillators

- 0.5-2.0 Ws/kg internal
- 5-10 Ws/kg external
- Small animal (<7 kg) 5-15 Ws internal, 50-100 Ws external
- Large animal (>10 kg) 20-80 Ws internal, 100-400 Ws external

Alternating-current Defibrillators

Small animal

- 30-50 V internal
- 50-100 V external

Chemical Defibrillation

1 mg potassium chloride and 6 mg acetylcholine/kg followed by 1 mL/10 kg of 10% calcium chloride

Unresponsive ventricular fibrillation

- Evaluate ventilation
- Evaluate chest or cardiac compression
- Repeat epinephrine and consider calcium chloride administration
- Administer sodium bicarbonate
- Administer lidocaine
- Repeat electrical defibrillation

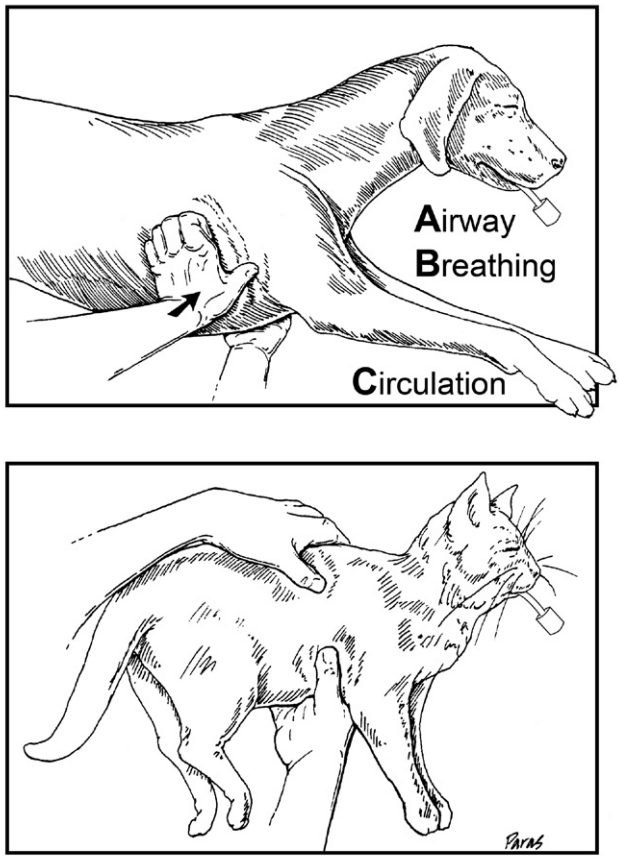


FIG. 29-3. Chest compression (about 100 compressions/min) in dogs and cats should be from side to side and should not be performed in animals with rib fractures; direct cardiac compression may be required.

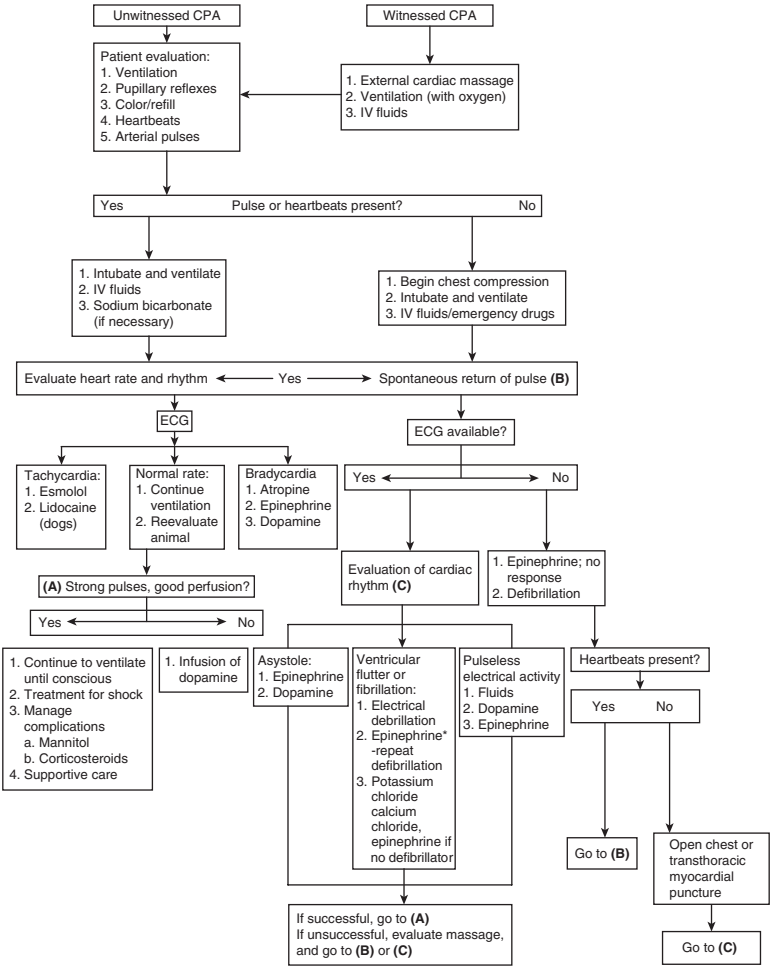


FIG. 29-4. Treatment of cardiopulmonary arrest. CPA, Cardiopulmonary arrest; IV, intravenous. *Vasopressin (0.8 IU/kg) has been used as an alternative to epinephrine.

TABLE 29-5 Essential Drugs Used in Managing Cardiopulmonary Complications

Generic Name	Trade Name	Beneficial Effects (recommended use)	Adverse or Side Effects	Dose and Route of Administration
VASOACTIVE AND CARDIOSTIMULATORY AGENTS				
Epinephrine HCl [1:1000]	Adrenaline	Positive inotrope; initiates heartbeats; increases heart rate and cardiac output; initially increases, then decreases, mean arterial blood pressure and coronary blood flow	Intense vasoconstriction of renal and splanchnic vasculature; causes decreased perfusion of these tissues; increases myocardial oxygen consumption and cardiac work; arrhythmogenic, may cause ventricular fibrillation	5-10 μg/kg IC 10-30 μg/kg IV 0.1-0.2 mL/20 kg IV, small animals 1-3 mL/450 kg IV, [1:1000], large animals
Norepinephrine	Levophed	Vasoconstrictor and positive inotrope; decreases or increases heart rate and cardiac output; increases mean arterial blood pressure and coronary blood flow	Intense vasoconstriction of renal and splanchnic vasculature; may decrease perfusion of these tissues; increases myocardial oxygen consumption and cardiac work; arrhythmogenic. Note: administered with vasopressin (0.0005-0.0010 μg/kg/min) in septic animals	0.01-0.4 μg/kg/min IV

Continued

TABLE 29-5 Essential Drugs Used in Managing Cardiopulmonary Complications—cont'd

Generic Name	Trade Name	Beneficial Effects (recommended use)	Adverse or Side Effects	Dose and Route of Administration
Dopamine HCl	Intropin	Positive inotrope; increases heart rate, cardiac output, and mean arterial blood pressure; improves blood flow to coronary, renal, and mesenteric circulation	May produce severe tachycardia if given rapidly; arrhythmogenic; vasoconstriction at higher doses	Increase dose rate until effective then adjust to minimum rate to attain the desired effect; add 6 mg to 250 mL 5% dextrose; drip slowly at rate of 2-15 μg/kg/min IV
Dobutamine HCl	Dobutrex	Positive inotrope; has lower chronotropic and vasopressor effect than dopamine	Tachyarrhythmias, vasoconstriction, and arrhythmias at higher doses	Give until effective, 1-10 μg/kg/min IV
Ephedrine sulphate	Ephedrine	Vasopressor; positive inotrope, chronotrope, vasoconstrictor	Tachycardia, hypertension	5-10 μg/kg IV to effect
Phenylephrine	Neosynephrine	Vasopressor	Hypertension, bradycardia, cardiac arrhythmias	0.1-1.000 μg/kg/min IV
Vasopressin	Pitressin	Vasopressor	Hypertension, cardiac arrhythmias	0.8 IU/kg once or twice IV
DRUGS USED SPECIfiCALLY TO INCREASE CONTRACTILITY				
Calcium chloride		Positive inotrope; used to treat inhalant anesthetic overdose, hyperkalemia, and PEA	May cause asystole; myocardial calcium overload; "stone" heart	0.05-0.10 mL/kg of the 10% solution IV, IC

Digoxin	Lanoxin	Positive inotrope; increased vagal tone; used in cases of CPA caused by congestive heart failure; treat supraventricular tachycardia	Arrhythmogenic; increases oxygen consumption; causes vasoconstriction when given IV	0.005-0.010 mg/kg IV; given in four divided doses; dose every hour; give until effective; monitor ECG
DRUGS USED TO COMBAT ACIDOSIS				
Sodium bicarbonate		Buffer acidosis; allows more effective defibrillation	Excessive administration may produce alkalosis, hyperosmolarity, paradoxical cerebrospinal fluid acidosis	1-2 mEq/kg IV, give until effective
DRUGS USED TO TREAT ACUTE CARDIAC ARRHYTHMIAS				
Atropine sulfate		Parasympatholytic effects; may correct supraventricular bradycardia or a slow ventricular rhythm by stimulating supraventricular pacemakers	May cause excessive tachycardia; increases myocardial oxygen consumption; lowers ventricular fibrillatory threshold; may predispose to sympathetic-induced arrhythmias	0.1-0.2 mg/kg IV
Glycopyrrolate	Robinul-V	Parasympatholytic (anticholinergic); may correct supraventricular bradycardia	May cause excessive tachycardia	0.005-0.010 mg/kg IV
Esmolol	Brevibloc	β_1-adrenergic blocker; treats supraventricular and ventricular tachycardias	Hypertension, bradycardia, heart failure	10-50 μg/kg/min IV

Continued

TABLE 29-5 Essential Drugs Used in Managing Cardiopulmonary Complications—cont'd

Generic Name	Trade Name	Beneficial Effects (recommended use)	Adverse or Side Effects	Dose and Route of Administration
Propranolol HCl	Inderal	β-adrenergic blocker; antiarrhythmic; may correct supraventricular and ventricular tachycardias	Decreases contractility, an important adverse effect; may increase airway resistance	1 mg diluted in 1 mL saline solution; this dilution is given as 0.05-0.10 mL boluses IV; give until effective
Lidocaine	Xylocaine	Ventricular antiarrhythmic	Dosage must be considerably decreased when used in cats	2-6 mg/kg dogs IV 0.5-1.0 mg/kg cats IV
Diltiazem	Cardizem	Calcium-channel blocker; treats supraventricular arrhythmia	Bradycardia hypotension	1-2 mg/kg PO
Sotalol	Betapace	Ventricular arrhythmia	Hypotension, proarrhythmia	1.0-3.0 mg/kg IV
Acetylcholine-potassium chloride cocktail		Chemical defibrillator	Parasympathomimetic side effects	6 mg/kg ACh + 1 mEq/kg KCl, IC
DRUGS USED TO STIMULATE VENTILATION				
Doxapram HCl	Dopram	Direct action on centers in the medulla	Respiratory alkalosis, hyperkalemia	1-4 mg/kg IV, 10 μg/kg/min; give until effective
DRUGS USED TO COMBAT CEREBRAL EDEMA				
Oxygen		Prevents vasodilation	May cause pulmonary edema with prolonged administration; may suppress ventilatory drive	2-4 L/min (small animal) 15 L/min (large animal)

Mannitol	20% Osmitrol	Osmotic diuretic; reduces cerebral edema	May overload the volume of the circulatory system, causing edema	1-2 g/kg IV
Dexamethasone	Azium	(See section on shock)		
DRUG USED TO COMBAT ACUTE PULMONARY EDEMA				
Furosemide	Lasix	Potent loop diuretic promoting loss of Na^+Cl^- and H_2O	May cause dehydration or lead to hypokalemic metabolic alkalosis if used excessively	1-2 mg/kg IV, 2-4 mg/kg IM
STEROIDS				
Prednisolone sodium	Solu-Delta-Cortef	Stabilizes lysosomal membranes; induces vasodilation; regulates fluid and electrolyte homeostasis		30 mg/kg IV
Dexamethasone	Azium SP	Increases cardiac output	May increase edema in cats with congestive heart failure; fluid administration rate generally should not exceed 90 mL/kg/hr; administer at high rates initially to improve venous return	8 mg/kg IV 20-40 mg/kg/hr; give until effective
ISOTONIC INTRAVENOUS FLUIDS				
Lactated Ringer's 0.9% saline solution		Expand the blood volume; hypotension; increase tissue perfusion	Fluid overload; hemodilution	As needed

Continued

TABLE 29-5 Essential Drugs Used in Managing Cardiopulmonary Complications—cont'd

Generic Name	Trade Name	Beneficial Effects (recommended use)	Adverse or Side Effects	Dose and Route of Administration
SPECIFIC DRUG ANTAGONISTS				
Naloxone	Narcan	Narcotic antagonist	None	50 μg/kg 0.02 mg/kg
Neostigmine	Prostigimine, Stiglyn	Cholinesterase inhibitor; used to reverse nondepolarizing neuromuscular blocking agents	Cholinergic effects; a parasympatholytic must be given before drug administration (e.g., atropine, glycopyrrolate)	
Pyridostigmine	Regonol	Cholinesterase inhibitor; used to reverse nondepolarizing neuromuscular blocking agents	Cholinergic effects; a parasympatholytic must be given before drug administration (e.g., atropine, glycopyrrolate)	0.1 mg/kg IV
Edrophonium	Tensilon	Cholinesterase inhibitor; used to reverse nondepolarizing neuromuscular blocking drugs	Same as neostigmine	0.2-1.0 mg/kg IV
Atipamezole	Antisedan	α_2-antagonist; used to reverse α_2-agonists	Excitement, disorientation	0.05-0.10 mg/kg IV
Tolazoline	Tolazine	Same as yohimbine but more selective for α_2-receptors	Excitement	2-4 mg/kg IV
Atipamezole	Antisedan			0.1-0.2 mg/kg IV
Flumazenil	Romazicon	Benzodiazepine antagonist	—	0.1 mg/kg IV

CPA, Cardiopulmonary arrest; *ECG*, electrocardiogram; *IC*, intracardiac; *IM*, intramuscularly; *IV*, intravenously; *PEA*, pulseless electric activity; *PO*, by mouth.

Euthanasia

30

"Sweet is true love though given in vain, and sweet is death that puts an end to pain."
ALFRED LORD TENNYSON

OVERVIEW

The decision to euthanize an animal is often made because the animal has incurable disease or uncontrollable pain. Such decisions are personal and emotional. Almost all drugs used for anesthesia have the capability of producing death, if a sufficient amount is administered. Anesthesia offers the advantage of producing total unconsciousness before cardiopulmonary arrest and the elimination of brain electrical activity. See American Veterinary Medical Association Guidelines on Euthanasia (www.avma.org).

General Considerations

I. Euthanasia is the act of inducing loss of consciousness and death without causing pain, distress, anxiety, or apprehension. The method used should result in cardiac and respiratory arrest and the loss of brain function.
  A. Death is defined as the cessation of all vital functions of the body including heartbeat, breathing, and brain activity
  B. Euthanasia often requires that the animal is sedated or physically restrained
  C. Methods of euthanasia
    1. Acceptable methods consistently produce a humane (showing compassion or benevolence; inflicting the minimum of pain) death when used as the sole means of euthanasia
    2. Conditionally acceptable methods are those techniques that might not consistently produce humane death by the nature of the technique or because of a greater potential for operator error
      a. Some conditionally acceptable methods involve greater risk for personnel

   b. Conditionally acceptable methods require training to ensure they are performed safely and humanely
3. Unacceptable methods are those techniques deemed inhumane under any condition or methods that pose an unacceptable risk to those applying the technique

D. In many species, capturing and immobilizing the animal for euthanasia may cause aesthetically unpleasant responses
1. Vocalization
2. Avoidance or aggressive behavior
3. Immobility (the animal may be frozen with fear)
   a. Some species (rabbits and chickens) may "play dead" (learned helplessness)
4. Urination and defecation, evacuation of anal sacs
5. Sweating, salivation
6. Skeletal muscle tremors, spasms, or shivering
7. Pupillary dilation
8. Tachycardia

E. Selection of a method of euthanasia depends on many factors:
1. The animal
   a. Species
   b. Size and weight
   c. Behavior and demeanor
2. Type of physical restraint required and available
   a. Anesthetized or unconscious animals may not require restraint
   b. The location of the animal may prevent the application of some methods
   c. Consideration should be given to moving an animal to a private space or facility with appropriate equipment
3. Owner preference, public perception
4. Experience, skill, number of available trained personnel, and degree of risk
5. Number of animals to be euthanized
6. Cost of drugs or equipment
7. Method of disposal of remains

F. Sedation or the administration of depressant drugs (e.g., α_2-agonists, opioids) is recommended before the administration of euthanizing drugs
1. The aesthetics of euthanasia are improved
2. Operator safety is enhanced particularly if the animal is excitable or vicious

3. Euthanasia in most large animals involves the induction of recumbency
   a. Euthanasia with pentobarbital in awake horses can be abrupt, appear frantic, and occasionally be dangerous without appropriate sedation
   b. Anesthesia can be induced with xylazine/ketamine prior to administration of pentobarbital

G. Pain perception requires a functional cerebral cortex and subcortical structures; pain-provoking stimuli in an unconscious animal may evoke reflex motor or sympathetic activity but the animal may not experience pain

H. Stress is defined as the effects of physical, physiologic, or emotional factors (stressors) that induce an alteration in homeostasis or adaptive state

I. Personnel who routinely perform euthanasia must have appropriate certification, training, and experience in humane restraint of the species of animal to be euthanized to ensure that pain and distress are minimized

Euthanasia Methods

I. Euthanizing agents include gaseous, chemical, and physical (e.g., mechanical, electrical) methods of producing death (Table 30-1)

II. Euthanizing agents produce death by one of three mechanisms
   A. Hypoxia; direct or indirect
   B. Direct depression of the central nervous system (anesthetic overdose)

TABLE 30-1 Acceptable Methods of Euthanasia by Species

Species	Agent and Method	Dose
Dog	Barbiturates*	100 mg/kg IV
	Inhalant anesthetics†	Overdose until effective
Cat	Barbiturates*	100 mg/kg IV
	Inhalant anesthetics†	
Horse	Barbiturates*	100 mg/kg IV
	Potassium chloride or magnesium sulfate concurrent with anesthesia	1-2 mmol/kg rapid IV or intracardiac administration
Ruminant	Barbiturates*	100 mg/kg IV
	Potassium chloride or magnesium sulfate concurrent with anesthesia	1-2 mmol/kg rapid IV or intracardiac administration

Continued

TABLE 30-1 Acceptable Methods of Euthanasia by Species—cont'd

Species	Agent and Method	Dose
Swine	Barbiturates*	100 mg/kg IV
	Carbon dioxide	30%
Camelid	Barbiturates*	100 mg/kg IV
Rabbit	Barbiturates*	100 mg/kg IV
	Inhalant anesthetics†	Overdose until effective
Rodents and other small mammals	Barbiturates*	100 mg/kg IV, IP if necessary
	Inhalant anesthetics†	Overdose until effective
Bird	Barbiturates*	100 mg IV, IP
	Inhalant anesthetics†	
Mink, fox, and other mammals produced for fur	Barbiturates*	100 mg/kg IV, IP
	Inhalant anesthetics†	Overdose until effective
Reptile	Barbiturates*	Sodium pentobarbital 60-100 mg/kg IV, IP
	Inhalant anesthetics† (in appropriate species‡)	Overdose until effective
Amphibian	Barbiturates*	Sodium pentobarbital 60-100 mg/kg IV, IP
	Inhalant anesthetics† (in appropriate species‡)	Overdose until effective
Zoo animals	Barbiturates*	100 mg/kg IV
	Inhalant anesthetics†	
Fish	Barbiturates*	Sodium pentobarbital 60-100 mg/kg IV, IP
	MS-222	>250 mg/L
Free-ranging wildlife	Barbiturates*	100 mg/kg IV or IP
	Inhalant anesthetics†	Overdose until effective

*Sodium pentobarbital fulfills the goals of euthanasia and is the most widely used method in veterinary practice. Dose is 100 mg/kg IV. Mechanical forms of euthanasia (gunshot; captive bolt) can be performed under appropriate circumstances but are discouraged.

†Inhalant agents should not be used alone in animals younger than 16 weeks old except to induce loss of consciousness, followed by the use of some other method to produce death.

‡Many reptiles and amphibians, including chelonians, are capable of holding their breath and converting to anaerobic metabolism. They can survive long periods of anoxia; death in these species may not occur even after prolonged inhalant exposure.

IP, Intraperitoneal; *IV*, intravenous.

C. Physical disruption of brain activity and destruction of neurons necessary for life (e.g., gunshot to the head)

III. The most common drug used for euthanasia of dogs, cats, horses, and cattle is pentobarbital at a dose of 100 mg/kg of body weight intravenously

IV. Gunshot and penetrating captive bolt gun in larger animal species
- A. When properly performed produces immediate brain-tissue destruction and death (www.vetmed.ucdavis.edu/vetext/inf-an/inf-an_emergeuth-horses.html)
  1. The device (gun, captive bolt) should be directed between the eyes and at an angle with the head so that the projectile travels directly toward the spinal canal
- B. Should be attempted only by trained and experienced individuals

V. Animals may have motor activity (muscle spasms; agonal breathing) after loss of consciousness with any method or technique
- A. This is reflex activity and is not perceived by the animal
- B. Activity is more often seen after hypoxic methods of euthanasia causing physical disruption of brain activity

Evaluation Criteria

I. Criteria for evaluation of acceptable methods of euthanasia
- A. Loss of consciousness and death should occur without causing pain, distress, anxiety, or apprehension
- B. The time from initiation of the euthanizing method to loss of consciousness should be short
- C. The manner of death should be consistent and predictable
- D. Death should be irreversible
- E. Method should be safe for personnel
  1. Emotional effects on observers and operators should be considered
- F. Result should be compatible with requirement and purpose
  1. Subsequent evaluation, examination, or use of tissues should be considered
- G. Drugs administered should be controlled and recorded
  1. Potential for abuse by humans should be considered
  2. Record-keeping requirements are significant
- H. Method should be compatible with the species, age, and health status
- I. Equipment, if used, should be easy to maintain in proper working order

J. Predators/scavengers must be prevented from consuming drug-contaminated remains
   1. Primarily a concern for pentobarbital
   2. Consumption of drug-containing remains by endangered species can result in fines and imprisonment

Unacceptable Drugs and Techniques

I. Unacceptable drugs: depolarizing and nondepolarizing muscle relaxants, strychnine, magnesium sulfate, and nicotine are intravenous drugs that are no longer recommended for euthanasia; their individual use as sole euthanizing agents is absolutely unwarranted
   A. Strychnine produces violent muscular contractions associated with extreme pain
   B. Magnesium sulfate and potassium chloride cause death from asphyxia and cardiovascular depression. They can be used to produce death in animals that are anesthetized.
   C. Nicotine produces convulsions before death and is extremely hazardous to personnel
   D. Neuromuscular blocking drugs (e.g., succinylcholine, atracurium) cause muscle paralysis (apnea) without unconsciousness
   E. Drugs that exhibit the following characteristics should not be used alone
      1. Drugs that do not produce unconsciousness
      2. Drugs that do not produce analgesia
      3. Drugs that have no anesthetic effect

II. Unacceptable techniques in conscious animals
   A. Manually applied blunt trauma to the head or strangulation
   B. Exsanguination
   C. Rapid freezing
   D. Air embolism
   E. Decompression
   F. Drowning
   G. Electrocution (stunning)

Methods of Confirming Death

I. Confirmation of death is paramount for professionals performing euthanasia
   A. Multiple indicators should be used
   B. Observations should be repeated over 5 to 10 minutes

II. Observe for cessation of vital signs

A. Cardiovascular function
   1. Loss of palpable pulses or thoracic "apex" beats
   2. Lack of heart sounds
   3. Lack of myocardial electrical (electrocardiographic) activity
      a. Electrical activity may be present without cardiac contractions
      b. Electrical activity may persist for several minutes after contractions have ceased
   4. Deterioration of the color of mucous membranes

B. Respiratory function
   1. Lack of respirations for at least 5 minutes (species dependent)

C. Central nervous system function
   1. Loss of ocular reflexes (palpebral, corneal)
   2. Lack of pupillary response to light
   3. Loss of electroencephalographic activity

Additional reading:
www.avma.org/KB/Policies/Documents/euthanasia.pdf

APPENDIX

I Physical Principles of Anesthesia

I. Laws

A. Boyle's law

$$\text{Volume} = \frac{k}{\text{Pressure}}; \quad V \times P = k$$

$$P_1V_1 = P_2V_2$$

B. Charles' law

$V = k + T \quad T = °\text{Kelvin (K)}$

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

C. Gay-Lussac's law

$P = k \times T \quad T = °K$

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

From above:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

D. Ideal Gas law

$$\frac{PV}{T} = n\frac{(1\,\text{atm})(22.412)}{273K}$$

$PV = nRT \quad R = 0.08206 \quad 1\,\text{atm}/°K \quad n = \text{g moles}$

E. Henry's law

$V = \alpha P \quad V = \text{volume of gas dissolved}$

$\alpha = \text{solubility coefficient}$

$P = \text{partial pressure}$

The solubility of a gas or vapor in a liquid (α) decreases as the temperature increases

F. Law of partial pressure (Dalton's law): Each gas in a mixture exerts the same pressure as it would exert if it alone occupied the same volume at the same temperature; because pressure

measurements cannot distinguish different molecules in a mixed sample, the contribution to total pressure made by a given constituent is in proportion to the number of molecules of that constituent

G. Graham's law: The velocity or rate of diffusion is inversely proportional to the square root of the density

II. Terms

A. Vapor pressure
   1. Tendency for a liquid to evaporate
   2. When a liquid and its vapor are in equilibrium, the partial pressure that the vapor exerts

B. Heat of vaporization: The amount of heat required for a liquid to evaporate

C. Volumes of a vapor

$$\frac{\text{Vapor pressure}}{\text{Total pressure}} \times 100 = \text{Vol\%}$$

D. Boiling point of a liquid: The temperature at which its vapor pressure is equal to the prevailing atmospheric pressure; generally stated for 760 mm Hg

E. Critical temperature: When a liquid is confined in a strong container, the temperature at which the contents of the container consist only of vapor

F. Critical pressure: When a liquid is confined in a strong container, the pressure that exists when the container has reached its critical temperature; liquid volumes may be converted to weight by the formula: volume (mL) × density (g/mL) = grams of liquid

G. Latent heat of vaporization: The amount of heat necessary to evaporate a quantity of liquid to its vapor state without any changes in temperature; expressed in calories per gram of liquid; this heat is stored in the vapor

III. Specific partition coefficients: The solubility coefficient may be expressed as follows:

A. Bunsen's absorption coefficient: Amount of gas (volume) at standard temperature and pressure that dissolves in one volume of liquid when the partial pressure of the gas above the liquid is 1 atm

B. Ostwald's solubility coefficient: The volume of gas absorbed by a unit volume of liquid when the partial pressure of the gas is 1 atm, the volume of gas being expressed at the temperature of the experiment

C. The partition coefficient
   1. May be expressed as the ratio of concentration of a substance in the gas phase and in the liquid phase (e.g., milligrams per milliliter)
   2. Partition coefficients are also used to relate the ratios of concentrations in any two phases that are in equilibrium
      a. Liquid-liquid (oil-water)
      b. Liquid-solid
      c. Gas-solid

IV. Useful tables (Tables A-1 through A-3)

V. Conversion equations for weight in kilograms to body surface area (m^2)

TABLE A-1 Standard Values and Equivalents*

	Metric Weights	
1 gram (g)	=	weight of 1 mL water at 4° C
1000 g	=	1 kilogram (kg)
0.1 g	=	1 decigram (dg)
0.01 g	=	1 centigram (cg)
0.001 g	=	1 milligram (mg)
0.001 mg	=	1 microgram (μg)
28.4 g	=	1 ounce (oz)
453.6 g	=	1 pound (lb)
16 oz	=	1 lb
	Metric Volume	
1 liter (L)	=	1 cubic decimeter (dL) or 1000 cubic centimeters (cc) or 1000 milliliter (ml)
0.1 liter	=	1 deciliter (dL)
0.001 liter	=	1 milliliter (mL)
	Metric Length	
1 meter (m)	=	100 centimeter (cm)
1 cm	=	10 millimeter (mm)
2.54 cm	=	1 inch (in)
30.48 cm	=	1 foot (ft)
0.91 m	=	1 yard (yd)
	Concentration	
1%	=	1 g/100 mL (10 mg/mL)

*International System (SI) units

TABLE A-2 Conversion Factors

SI Unit	Old Unit	Conversion Factors: To SI (Exact)	Conversion Factors: SI To Old (Approximate)
kPa	mm Hg	0.133	7.5
kPa	1 standard atmosphere (approximately 1 Bar)	101.3	0.01
kPa	cmH_2O	0.0981	10
kPa	Lb/sq inch	6.89	0.145

Measurement	SI Unit	Old Unit	Conversion Factors: To SI (Exact)	Conversion Factors: SI To Old (Approximate)
BLOOD				
Acid-base				
PCO_2	kPa	mm Hg	0.133	7.5
PO_2	kPa	mm Hg	0.133	7.5
Base excess	mmol/L	mEq/L	Numerically equivalent	
PLASMA				
Sodium	mmol/L	mEq/L	Numerically equivalent	
Potassium	mmol/L	mEq/L	Numerically equivalent	
Magnesium	mmol/L	mEq/L	0.5	2.0
Chloride	mmol/L	mEq/L	Numerically equivalent	
Phosphate (inorganic)	mmol/L	mEq/L	0.323	3.0
Creatinine	μmol/L	mg/100 mL	88.4	0.01
Urea	mmol/L	mg/100 mL	0.166	6.0
SERUM				
Calcium	mmol/L	mg/100 mL	0.25	4.0
Bilirubin	μmol/L	mg/100 mL	17.1	0.06
Total protein	g/L	g/100 mL	10.0	0.1
Albumin	g/L	g/100 mL	10.0	0.1
Globulin	g/L	g/100 mL	10.0	0.1

TABLE A-3 Alveolar and Arterial Gas Pressures in Healthy Subjects at Altitude

				Alveolar Gas Tensions (mm Hg)				*Arterial Gas Tensions (mm Hg)*			
Altitude (Feet)	**Atmospheric Pressure (mm Hg)**	**PIO_2 (mm Hg)**	**Sea Level FIO_2**	**H_2O**	**CO_2**	**N_2**	**O_2**	**CO_2**	**O_2**	**SpO_2**	**Inspired FIO_2 Needed To Yield Sea Level PIO_2**
Sea level	760	149	20.9	47	37	574	102	40	95	97	20.9
6,000	609	118	16.6	47	36	452	74	—	—	—	26.5
8,000	565	108	15.1	47	37	416	65	38	56	89	28.8
10,000	523	100	14.0	47	36	379	61	—	—	—	31.3

PIO_2, Inspired oxygen tension; *FIO_2*, fraction of inspired oxygen concentration.

A. Dogs

$$\text{Approximate body surface area (BSA; } m^2) = \frac{10.1 \times (\text{Body weight in grams})^{\frac{2}{3}}}{10000}$$

B. Cats

$$\text{Approximate BSA } (m^2) = \frac{10.0 \times (\text{Body weight in grams})^{\frac{2}{3}}}{10000}$$

C. Horses

$$\text{Approximate BSA } (m^2) = \frac{10.5 \times (\text{Body weight in grams})^{\frac{2}{3}}}{10000}$$

APPENDIX

II Drug Schedules

Controlled substances are obtained by prescription and must be used for legitimate medical purposes. The prescriber must have authorization from appropriate legal authorities, the Controlled Substances Act (CSA), to handle controlled substances. The CSA is the legal foundation of the government's fight against the abuse of drugs and other substances. All individuals and firms that are registered are required to maintain complete and accurate inventories and records of all transactions involving controlled substances, as well as security for the storage of controlled substances.

The CSA places all substances that are regulated under existing federal law into one of five schedules based on the substance's medicinal value, harmfulness, and potential for abuse or addiction. The CSA list of controlled substance schedules describes the basic or parent chemical and does not describe the salts, isomers and salts of isomers, esters, ethers, and derivatives that might be controlled substances.

TABLE A-1 Drug Schedules

Scheduled Drugs	Labeling Symbols	Descriptions	Examples
Schedule I	CI or C-I	No accepted medical use in the United States High potential for abuse A lack of accepted safety for use	Heroin, dihydromorphine, etorphine (except hydrochloride salt)
Schedule II	CII or C-II	Accepted medical uses in the United States (may include severe restrictions) High potential for abuse, which may lead to severe psychological or physical dependence	Morphine, meperidine, methadone, oxymorphone, hydromorphone, etorphine hydrochloride, fentanyl, pentobarbital

TABLE A-1 Drug Schedules—cont'd

Scheduled Drugs	Labeling Symbols	Descriptions	Examples
Schedule III	CIII or C-III	Accepted medical uses in the United States Lesser degree of abuse potential than Schedules I and II Abuse may lead to moderate or low physical dependence or high psychological dependence	Thiopental, tiletamine and zolazepam, ketamine, buprenorphine, anabolic steroids
Schedule IV	CIV or C-IV	Accepted medical uses in the United States Low potential for abuse of Schedule III Abuse may lead to limited physical or psychological dependence	Chloral hydrate, diazepam, midazolam, pentazocine, phenobarbital, butorphanol
Schedule V	CV or C-V	Accepted medical uses in the United States Low potential for abuse of Schedule IV Abuse leads to limited physical or psychological dependence	

The salts, isomers and salts of isomers, esters, ethers, and derivatives of these substances may also be controlled substances.

SCHEDULE I

The drug or other substance has a high potential for abuse
The drug or other substance has no currently accepted medical use in treatment in the United States
There is a lack of accepted safety for use of the drug or other substance under medical supervision

SCHEDULE II

The drug or other substance has a high potential for abuse

The drug or other substance has a currently accepted medical use in treatment in the United States or a currently accepted medical use with severe restrictions
Abuse of the drug or other substances may lead to severe psychological or physical dependence

SCHEDULE III

The drug or other substance has a potential for abuse less than the drugs or other substances in Schedules I and II
The drug or other substance has a currently accepted medical use in treatment in the United States
Abuse of the drug or other substance may lead to moderate or low physical dependence or high psychological dependence

SCHEDULE IV

The drug or other substance has a low potential for abuse relative to the drugs or other substances in Schedule III
The drug or other substance has a currently accepted medical use in treatment in the United States
Abuse of the drug or other substance may lead to limited physical dependence or psychological dependence relative to the drugs or other substances in Schedule III

SCHEDULE V

The drug or other substance has a low potential for abuse relative to the drugs or other substances in Schedule IV
The drug or other substance has a currently accepted medical use in treatment in the United States
Abuse of the drug or other substance may lead to limited physical dependence or psychological dependence relative to the drugs or other substances in Schedule IV

REFILLS (SCHEDULES III AND IV)

A prescription for a controlled substance listed in Schedule III or IV may not be filled or refilled more than six months after the original date of issue of the prescription. They may not be refilled more than five times. Each refill must be entered on the back of the original prescription or other appropriate document (medication record).

When retrieving the prescription number, the following information should be available: the name and dosage form of the controlled substance, the date filled or refilled, the quantity dispensed, initials of the registered pharmacist for each refill, and the total number of refills for that prescription to date.

As an alternative to the procedures, an automated data processing system may be used for the storage and retrieval of refill information for prescription orders for controlled substances in Schedules III and IV.

ORAL REFILLS (SCHEDULES III AND IV)

The prescribing practitioner may authorize additional refills of Schedule III or IV controlled substances on the original prescription through an oral refill authorization transmitted to the pharmacist. The total number of refills (quantity) allowed, including the amount of the original, may not exceed five refills or SIX months from the original date.

A. A new and separate prescription must be issued for any more than five refills or after six months from the date of issue of the original prescription

B. The pharmacist obtaining the oral authorization records on the reverse of the original prescription the date, quantity of refill, and number of additional refills authorized and then initials the prescription showing who received the authorization from the prescribing practitioner that issued the original prescription

C. The quantity of each refill must be less than or equal to the original quantity authorized

PARTIAL FILLING OF PRESCRIPTIONS (CLASSES III, IV, AND V)

Partial prescriptions must be recorded in the same manner as refills.

The total quantity of partials may not exceed the total quantity prescribed.

Schedules III, IV, and V drugs may not be dispensed more than six months past the original date of the prescription.

LABELING

A controlled substance in Schedule II must be labeled with the pharmacy's name and address, serial number and date of filling, the patient's and physician's names, directions for use, and any cautionary statements.

DISPOSAL

Any person in possession of any controlled substance and desiring or required to dispose of such substance may request from the Special Agent in Charge of the Administration in the area in which the person is located for authority and instructions to dispose of such substance.

A. If the person is a registrant, list the controlled substances on DEA form 41 (Registrants Inventory of Drugs Surrendered) and submit three copies to the Special Agent in Charge of Administration

B. If the person is not a registrant, submit a letter that includes the name and address of the person; the name and quantity of each controlled substance to be disposed of; how the applicant obtained the substance and the name, address, and registration number of the Special Agent in Charge of Administration.

If you need to transfer Schedule II substances, the receiving registrant must issue form DEA 222 (Official Order Forms–Schedules I & II) to the registrant transferring the drugs. The transfer of Schedule III-V controlled substances must be documented in writing to show the drug name, dosage form, strength, quantity, and date transferred.

References:

http://www.dea.gov

http://www.deadiversion.usdoj.gov

Guiding Principles for Research Involving Animals and Human Beings

APPENDIX III

RECOMMENDATIONS FROM THE DECLARATION OF HELSINKI (UPDATED 2008)

I. Basic Principles
- A. Clinical research must conform to the moral and scientific principles that justify medical research and should be based on laboratory and animal experiments or other scientifically established facts.
- B. Clinical research should be conducted only by scientifically qualified persons and under the supervision of a qualified medical person.
- C. Clinical research cannot legitimately be carried out unless the importance of the objective is in proportion to the inherent risk to the subject.
- D. Every clinical research project should be preceded by careful assessment of inherent risks in comparison to foreseeable benefits to the subject or to others.
- E. Special caution should be exercised by the doctor in performing clinical research in which the personality of the subject is liable to be altered by drugs or experimental procedure.
- F. All biomedical research should address the "three Rs": reduction, refinement, replacement.

II. Clinical Research Combined with Professional Care
- A. In the treatment of the sick person, the doctor must be free to use a new therapeutic measure, if in his judgment it offers hope of saving life, reestablishing health, or alleviating suffering. If at all possible, consistent with patient psychology, the doctor should obtain the patient's freely given consent after the patient has been given a full explanation. In case of legal incapacity, consent should also be procured from the legal guardian; in case of physical incapacity the permission of the legal guardian replaces that of the patient.
- B. The doctor can combine clinical research with professional care, the objective being the acquisition of new medical

knowledge, only to the extent that clinical research is justified by its therapeutic value for the patient.

III. Nontherapeutic Clinical Research

A. In the purely scientific application of clinical research carried out on a human being, it is the duty of the doctor to remain the protector of the life and health of that person on whom clinical research is being carried out.

B. The nature, the purpose, and the risk of clinical research must be explained to the subject by the doctor.

C. Clinical research on a human being cannot be undertaken without his free consent after he has been informed; if he is legally incompetent, the consent of the legal guardian should be procured.

D. The subject of clinical research should be in such a mental, physical, and legal state as to be able to exercise fully his power of choice.

E. Consent should, as a rule, be obtained in writing. However, the responsibility for clinical research always remains with the research worker; it never falls on the subject even after consent is obtained.

F. The investigator must respect the right of each individual to safeguard his personal integrity, especially if the subject is in a dependent relationship to the investigator.

G. At any time during the course of clinical research the subject or his guardian should be free to withdraw permission for research to be continued. The investigator or the investigating team should discontinue the research if in his or their judgment, it may, if continued, be harmful to the individual.

Reference: **http://history.nih.gov/laws/pdf/helsinki.pdf**

GUIDING PRINCIPLES IN THE CARE AND USE OF ANIMALS

Approved by the Council of The American Physiological Society*

Animal experiments are to be undertaken only with the purpose of advancing knowledge. Consideration should be given to the

*The Guiding Principles for the Care and Use of Animals are based on principles formulated by Walter B. Cannon in 1909. The APS Council first adopted them in 1953. Latest revision approved July 2000.

appropriateness of experimental procedures, species of animals used, and number of animals required.

Only animals that are lawfully acquired shall be used in laboratory research, and their retention and use shall be in every case in compliance with federal, state, and local laws and regulations, and in accordance with the Institution for Laboratory Animal Research (ILAR) *Guide for the Care and Use of Laboratory Animals.*[†]

Animals used in research and education must receive every consideration for their comfort; they must be properly housed, fed, and their surroundings kept in a sanitary condition.

The use of animals must be in accordance with the *ILAR Guide for the Care and Use of Laboratory Animals.* Appropriate anesthetics must be used to eliminate sensibility to pain during all surgical procedures. Drugs that produce muscle paralysis are not anesthetics and they must not be used alone for surgical restraint, but may be used in conjunction with drugs known to produce adequate anesthesia. The care and use of animals shall be such as to minimize discomfort and pain. All measures to minimize pain and distress that would not compromise experimental results may be employed.

If the study requires the death of an animal, the most humane euthanasia method consistent with the study must be used.

When animals are used by students for their education or the advancements of science, such work shall be under the direct supervision of an experienced teacher or investigator.

Reference: http://www.the-aps.org/pa/humane/pa_aps_guiding.htm

[†]Institute for Laboratory Animal Research (ILAR). *Guide for the Care and Use of Laboratory Animals.* Washington, D.C.: National Academy Press, 1996.

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Equivalents of Centigrade and Fahrenheit Thermometric Scales

Centigrade Degree	Fahrenheit Degree	Centigrade Degree	Fahrenheit Degree
–17	+1.4	14	57.2
–16	3.2	15	59.0
–15	5.0	16	60.8
–14	6.8	17	62.6
–13	8.6	18	64.4
–12	10.4	19	66.2
–11	12.2	20	68.0
–10	14.0	21	69.8
–9	15.8	22	71.6
–8	17.6	23	73.4
–7	19.4	24	75.2
–6	21.2	25	77.0
–5	23.0	26	78.8
–4	24.8	27	80.6
–3	26.6	28	82.4
–2	28.4	29	84.2
–1	30.2	30	86.0
0	32.0	31	87.8
+1	33.8	32	89.6
2	35.6	33	91.4
3	37.4	34	93.2
4	39.2	35	95.0
5	41.0	36	96.8
6	42.8	37	98.6
7	44.6	38	100.4
8	46.4	39	102.2
9	48.2	40	104.0
10	50.0	41	105.8
11	51.8	42	107.6
12	53.6	43	109.4
13	55.4	44	111.2
		45	113.0

Conversion equations: °C = (°F-32) × 5/9, °F = (°C × 9/5) + 32; freezing point are 0° C and 32° F; boiling points are 100° C and 212° F.