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Anesthesia for Pediatric Patients

CONTINUING EDUCATION

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Veterinary neonatal and pediatric patients pose a unique set of perianesthetic management challenges for the veterinary anesthetist. Challenges range from the patients' immature physiologic system and altered handling of anesthetic and analgesic drugs to their small size, which makes IV catheter placement and endotracheal (ET) intubation potentially difficult. Even agreement on the veterinary definitions of *neonatal* and *pediatric* has been challenging. According to the American Animal Hospital Association (AAHA) life stage guidelines for dogs and cats, the neonatal stage extends from birth to weaning (~4 weeks of age) and the pediatric stage is generally from weaning until sexual maturity (~6 months of age, depending on breed and species).[1,2]

The clinical and therapeutic challenges presented by this subset of patients make it important that veterinary technicians understand the unique anatomic, physiologic, and pharmacologic differences in these patients to help formulate and provide the most appropriate anesthetic regimen.

PHYSIOLOGY

Neonatal and pediatric anesthetic patients have a limited reserve capacity in most physiologic systems. The cardiopulmonary system undergoes rapid and dramatic changes at the time of birth to support life during the transition from intrauterine physiology to adult physiology.[3] Neonatal and

WARM UP
Wrapping the pediatric patient in a warm towel can reduce the stress of restraint.

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pediatric patients are highly dependent on heart rate to maintain cardiac output and blood pressure.[4] They have less functional contractile tissue, limited cardiac reserve, and low ventricular compliance and therefore a reduced ability to increase stroke volume.[5] The sympathetic nervous system is underdeveloped, and these patients may have poor vasomotor control and reduced baroreceptor reflexes, which make them less able to tolerate blood loss and maintain blood pressure.[6] Bradycardia may therefore profoundly affect cardiac output and subsequently blood pressure. Although they are likely to rapidly respond to fluid loading, pediatric animals are less tolerant of fluid overload than adult dogs and cats.

Pulmonary reserve is also limited in pediatric patients. Compared with adults, anatomic differences such as a large tongue and less rigid airway cartilage can predispose pediatric patients to upper airway obstruction. Additionally, the ribcage is more pliable, the intercostal muscles weaker, the lungs less compliant, and the overall work of breathing is greater than in adults, thus facilitating airway collapse and respiratory fatigue.[3,7] Neonates have a reduced inspiratory reserve volume compared with adults, and increases in minute volume are achieved by increasing respiratory rate.[3] Functional residual capacity is reduced, respiratory chemoreceptors are immature, and oxygen demand is decreased, all of which predispose young animals to be at risk for rapid desaturation and hypoxemia during the perianesthetic period.[7] The susceptibility of young puppies and kittens to hypoxemia and respiratory fatigue necessitates oxygen supplementation throughout the anesthetic period and highlights the importance of careful monitoring of the respiratory system so that intermittent positive-pressure ventilation can be swiftly commenced if required.

The renal and hepatic systems are immature in very young patients. One of the main considerations for sedation and anesthesia is the metabolism, biotransformation, and excretion of drugs. An exaggerated effect and prolonged duration of action may be observed, and the technician may need to adjust and reduce dose rates and dosing intervals accordingly. Pediatric patients are prone to hypoglycemia because of minimal glycogen stores and poor gluconeogenesis.[8] Blood glucose monitoring and the administration of glucose-containing fluids may be beneficial during anesthesia. Renal function is also reduced compared with adult dogs and cats, adding to the reduced tolerance of fluid overloading and hypotension.

Thermoregulation is impaired in pediatric patients, and their larger body surface area relative to body weight and minimal fat reserves make them extremely vulnerable to hypothermia. In addition, most anesthetic agents affect the thermoregulatory center, and hypothermia may result. This can produce many deleterious effects, including decreased metabolic rate, increased susceptibility to infection, myocardial depression, respiratory depression, and delays in drug metabolism. Hypothermia significantly reduces the minimum alveolar concentration (MAC) of inhalational agents because of the decrease in metabolic rate.

TECHPOINT

In very small patients, an uncuffed ET tube may be preferable to maximize airway diameter and decrease resistance of breathing.

PREANESTHESIA PREPARATION

A complete physical examination is the cornerstone for any animal undergoing sedation or anesthesia. From the observations that are noted during this examination, the technician will be able to formulate the appropriate anesthetic plan.

Because of the minimal glycogen stores in the liver of the pediatric patient, withholding of food should be kept to a minimum. Unweaned puppies and kittens should not be fasted, and patients older than 6 weeks of age that are eating solid food need to be fasted only for a maximum of 3 to 4 hours before general anesthesia.[5] Prolonged fasting of these patients may result in hypoglycemia and dehydration and predispose them to hypothermia. Withholding of water is unnecessary.

The minimum laboratory evaluations should include packed cell volume, total protein, and blood glucose. Further evaluation of the patient's biochemical and hematologic status should be performed if indicated. Any fluid deficits or electrolyte imbalances should be corrected before anesthesia if possible. If possible, avoid repeated blood sampling, which may cause volume depletion in a very small patient.

Equipment

When planning to induce anesthesia in a pediatric patient, the correct equipment must be available. A selection of ET tubes of appropriate sizes should be readily accessible, along with a laryngoscope with a good light source and an appropriately sized blade. In very small patients, an uncuffed ET tube

may be preferable to maximize airway diameter and decrease resistance of breathing. If a cuffed ET tube is used, care must be taken not to overinflate the cuff because the tracheal tissue is very fragile. The use of laryngeal mask airway has been reported in kittens; however, the incidence of lower esophageal reflux was greater when compared with ET tubes.[9]

Owing to the small patient size and tidal volume, an increase in apparatus dead space is of significant concern. Causes of increased dead space include ET tubes that are too long and inappropriately sized wye-piece and capnograph connectors. **FIGURE 1** demonstrates a capnograph with rebreathing due to an increase in apparatus dead space in a small patient. Therefore, oxygen supply and a breathing circuit with a pediatric-sized wye-piece and bag should be available to assist with ventilation in small patients. Nonrebreathing systems may be a better choice in most of these patients to reduce breathing resistance and to facilitate faster changes in anesthetic concentration if inhalational agents are used. Unfortunately, the fresh high gas flow rate required by these circuits (2–3 times respiratory minute volume) may predispose the patient to hypothermia. Because of the high risk of desaturation in these patients, the importance of preoxygenation with an appropriately sized mask before induction of anesthesia cannot be overemphasized.

Equipment for monitoring the various organ systems during the perianesthetic period should be available and used until the patient has recovered and is able to maintain normal homeostasis. To reduce the risk of accidental fluid overload, equipment for administering IV fluids, such as pediatric burettes, fluid pumps, and syringe pumps, is advisable.

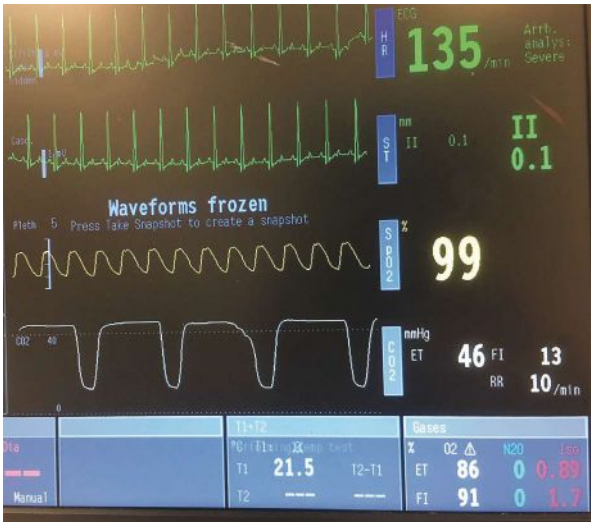

FIGURE 1. Increased inspired carbon dioxide due to an increase in apparatus dead space in a small patient.

An accurate weight for all patients is of the utmost importance, particularly for small patients, in which an overdose of fluids or drugs can have a catastrophic effect. With very small patients, it is advisable to use a small scale that can give an accurate weight in grams **(FIGURE 2)**.

PREMEDICATION

Neonatal patients are seldom premedicated; however, with the possible exception of extremely debilitated or ill patients, premedication is beneficial in pediatric/young dogs and cats. The use of a balanced drug combination can alleviate stress and significantly decrease the subsequent amounts of induction and maintenance agents required. Drugs that are short acting and reversible are recommended.

Drug selection and dose depend on the patient's age and physiologic status. In very young patients, the blood–brain barrier is more permeable, and central nervous system responses to drug administration may be exaggerated. The altered drug uptake, metabolism, distribution, and excretion of drugs by neonatal patients compared with pediatric and adult animals should also be taken into account. Regardless of the drug chosen, care must be taken with drug doses because this subset of patients is also less able to tolerate absolute or relative overdoses.

FIGURE 2. A puppy being weighed on an infant scale for accuracy.

The 4 main classes of drugs used as premedicants in pediatric patients are opioids, benzodiazepines, anticholinergics, and tranquilizers (TABLE 1). These drugs can be used alone or in combination.

Opioids

Opioids in general have very little effect on cardiac contractility but may produce a vagally mediated reduction in heart rate. Consequently, anticholinergic drugs are often coadministered with opioids.[5,7] The μ agonists (fentanyl,morphine, methadone, hydromorphone, and oxymorphone) provide the best analgesia but cause greater cardiovascular and respiratory depression than the partial μ agonists (buprenorphine) and the κ agonist/μ antagonists (butorphanol). These latter drugs provide only moderate analgesia but may be a more appropriate choice depending on the procedure and analgesic requirements. Full μ agonists may be reversed with specific antagonists such as naloxone if undesirable or prolonged drug effects occur.

Benzodiazepines

Benzodiazepines usually do not provide reliable sedation in healthy adult patients, but they are often quite effective in young patients. Midazolam and diazepam cause minimal cardiovascular depression and provide good muscle relaxation. Benzodiazepines do not provide any analgesia, so they are best used in combination with an opioid. Similar to opioids, benzodiazepines may be reversed with the antagonist flumazenil if required.

TABLE 1 Suggested Drug Doses for Pediatric Small Animals[a]

CLASS	DOSE (MG/KG) AND ROUTE	COMMENTS
ANTICHOLINERGICS		
Atropine	0.02–0.04 SC, IM, IV	Anesthetic adjuvant, treatment/prevention of bradycardia
Glycopyrrolate	0.01–0.02 SC, IM, IV	
BENZODIAZEPINES AND TRANQUILIZERS		
Diazepam	0.1–0.4 IV	IM, SC uptake unreliable; more effective when used in conjunction with an opioid
Midazolam	0.1–0.3 SC, IM, IV	More effective when used in conjunction with an opioid; shorter duration of action than diazepam
Flumazenil	0.1 IV	Benzodiazepine antagonist, short duration of action
Acepromazine	0.005–0.02 SC, IM, IV	Use with caution
OPIOIDS (use lower-end doses in cats)		
Methadone	0.05–0.3 SC, IM, IV	Good analgesia
Morphine	0.05–0.25 SC, IM	Good analgesia; vomiting may occur
Buprenorphine	0.005–0.02 SC, IM, IV	Slow onset of action
Butorphanol	0.1–0.3 SC, IM, IV	Mild pain only, may provide good sedation
Hydromorphone	0.03–0.07 SC, IM, IV	Good analgesia
Oxymorphone	0.03–0.07 SC, IM, IV	Good analgesia
Naloxone	0.01–0.1 IV	Opioid antagonist; all analgesia reversed, short duration of action
INDUCTION AGENTS[b]		
Propofol	1–4 IV	Hypotension, apnea common
Ketamine with or without diazepam	0.15–0.3/1.5–3 IV	
Etomidate	1–2 IV	
Alfaxalone	1–2 IV	

[a]Doses are extrapolated from adult doses. Combining drug groups provides balanced premedication. Drug doses should be further reduced for neonatal patients.
[b]Induction dose rates are for premedicated patients and should be titrated slowly to effect.

TECHPOINT

All clinically used inhalation agents produce some degree of dose-related cardiovascular and respiratory depression.

Anticholinergics

Anticholinergics are often indicated in neonatal and pediatric patients.[5,7] Because cardiac output in pediatric patients depends on heart rate, care should be taken to maintain heart rate. The use of atropine or glycopyrrolate may also be indicated in patients with high vagal tone or in procedures that are likely to stimulate a vagal reflex.

Tranquilizers

Acepromazine. Although acepromazine, a phenothiazine, is one of the most common drugs used in premedication in veterinary medicine, it should mostly be avoided in very young patients. It may cause hypotension and heat loss due to vasodilatation, and young patients are less able to compensate for these effects.

α_2-Adrenergic Agonists. The use of α_2-adrenergic agonists is best avoided in neonatal and pediatric dogs and cats owing to their potential to cause significant vasoconstriction and bradycardia. This is of particular importance in pediatric patients because of their rate-dependent cardiac output.

TABLE 1 lists suggested dosages of commonly used drugs for pediatric patients.

ANESTHETIC INDUCTION AND MAINTENANCE

Induction of anesthesia is achieved by the administration of injectable drugs or by the use of inhalational agents. Preoxygenation with 100% oxygen for at least 3 minutes using a facemask is recommended before the induction of anesthesia. Injectable drugs have the benefit of minimizing patient stress and causing a rapid loss of consciousness, which facilitates rapid control of the airway. However, venous access is required for administration, and this may prove challenging in conscious pediatric patients.

Injectable Drugs

The injectable drugs commonly used as induction agents are propofol, ketamine/diazepam, etomidate, and alfaxalone (TABLE 1). All injectable anesthetics have side effects that need to be considered when selecting the most appropriate drug.

All the injectable drugs require some degree of hepatic metabolism and renal clearance. When used in patients with immature renal and hepatic function, duration of action and recovery may be prolonged. An exception may be propofol because it has some degree of extrahepatic metabolism.

Accurate dosing of injectable induction agents is important. It is often beneficial to dilute the concentration of a particular drug with a compatible diluent to assist in titration.

All of the injectable agents have the potential to produce respiratory depression, so the veterinary technician needs to be able to take rapid control of the airway, supply oxygen, and ventilate when necessary.

Propofol

Propofol is a short-acting hypnotic agent that can be used for the induction and maintenance of anesthesia via incremental doses or infusion. It can cause dose-dependent bradycardia, vasodilatation, and respiratory depression and should be titrated to effect. Propofol is highly lipid soluble and requires hepatic metabolism, although some extrahepatic metabolism does occur.

Ketamine

Ketamine, a dissociative anesthetic, is often used in combination with a benzodiazepine as an induction agent. Ketamine has a rapid onset of action, causes minimal cardiovascular depression, and provides a short duration of analgesia. Ketamine often produces a transient increase in blood pressure and cardiac output due to stimulation of the sympathetic nervous system.[10]

Etomidate

Etomidate is a short-acting, nonbarbiturate IV anesthetic agent. It causes minimal adverse cardiovascular effects and is less likely to cause a significant drop in blood pressure than other induction agents. Etomidate produces minimal respiratory depression.

Alfaxalone

Alfaxalone in cyclodextrin (Alfaxan; alfaxan.com) is a neurosteroid agent that interacts with the γ-aminobutyric acid (GABA) type A receptor to produce anesthesia and muscle relaxation. At clinical doses it has good cardiovascular stability and causes minimal respiratory depression.[11,12] Alfaxalone was found suitable for use as an anesthetic induction agent in cats and dogs <12 weeks of age.[13,14] Cats <12 weeks of age were reported to better maintain heart rate when anesthesia was maintained with alfaxalone alone compared with an alfaxalone/isoflurane group.[14] Maintenance anesthesia using alfaxalone

may be of particular value in pediatric patients because cardiac output is heart rate dependent.

Inhalation Agents

All clinically used inhalation agents produce some degree of dose-related cardiovascular and respiratory depression. Isoflurane and sevoflurane are sometimes used for induction of anesthesia when IV or intraosseous access cannot be obtained. Sevoflurane has a lower solubility in blood than isoflurane, resulting in more rapid uptake (induction) and elimination (recovery). A small, well-fitting facemask with minimal dead space should be used for inhalation induction **(FIGURE 3)**. Wrapping the patient in a warm towel can reduce the stress of restraint. Uptake of anesthetic is rapid in the neonate, and the therapeutic index is narrow, so care must be taken not to overdose the patient.

Local Anesthetic Techniques

Local anesthetic techniques can be used to provide analgesia and anesthesia and to reduce the dose requirement of maintenance anesthetic agents. Because of the small size of veterinary neonatal and pediatric patients, the potential to overdose the patient and cause toxicosis exists. Therefore, the correct dose of local anesthetic (mass of drug per kilogram of body weight) should be carefully calculated, checked, and recorded.

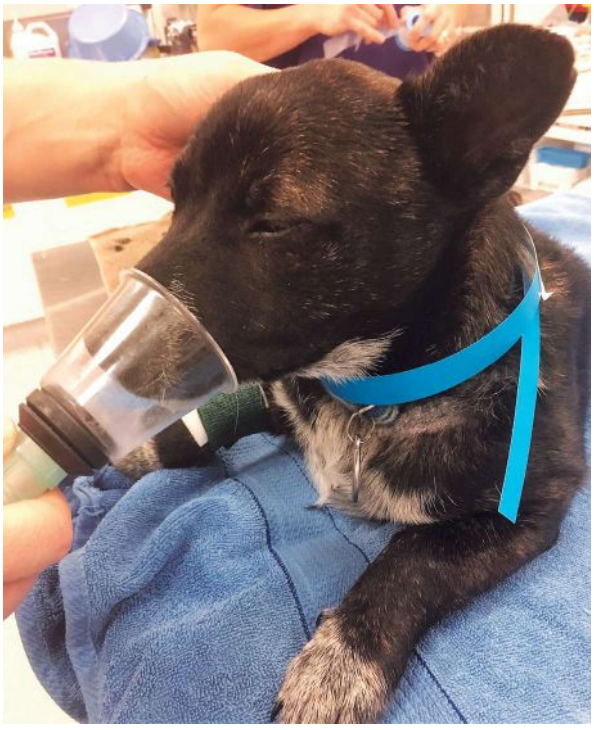

FIGURE 3. A small well-fitting mask with minimal dead space should be used to preoxygenate and/or for inhalant induction.

TECHPOINT

The width of the occlusion cuff should be approximately 40% of the circumference of the limb. An incorrectly sized cuff will result in a falsely high or low reading.

SUPPORT AND MONITORING

The goal of monitoring is to provide information to aid technicians in assessing the patient's physiologic status and providing the most appropriate anesthesia/analgesia plan for each patient. When developing a plan, the anesthetist should identify any potential disturbances that may occur under anesthesia, such as hypotension and hypothermia. The technician can then formulate the best approach to avoiding these physiologic changes, taking into account the signalment and current health status of the patient.

In veterinary medicine today, we have many electronic monitoring devices, but all monitors have limitations and should never replace a skilled, knowledgeable technician. When monitoring, one measurement gives a window into a dynamic situation, whereas repeated measurements provide a better indication of the dynamic picture. Trends have more meaning than single values.

Tissue perfusion can be assessed subjectively by pulse quality, capillary refill time, and mucous membrane color. Heart rate and rhythm can be assessed using a stethoscope, an esophageal stethoscope, or electrocardiography.

Blood pressure can be monitored invasively via an arterial catheter and transducer, but this can be technically challenging in a smaller patient. Noninvasive measurements of blood pressure (NIBP) are performed using a Doppler or oscillometric monitor. NIBP measurement may not always accurately predict blood pressure, and no treatment decision should be based on one measurement alone[15]; however, these monitors are useful for monitoring general blood pressure trends. Care must be taken to choose the correct size of occlusion cuff. The width of the cuff should be approximately 40% of the circumference of the limb. An incorrectly sized cuff will result in a falsely high or low reading.

Pulse oximetry gives an indication of the adequacy of circulation and oxygenation. A pulse oximeter indicates

the presence of pulsatile blood flow. Peripheral vasoconstriction, decreases in pulse amplitude, or arrhythmias are likely to affect signal quality.

Respiratory function can be subjectively assessed by respiratory rate and depth. Capnography provides a measurement of the carbon dioxide content of respiratory gases and therefore is a good indicator of the adequacy of respiratory function. Accuracy can be hampered by small tidal volumes in pediatric patients as well as the dilutional effect of high fresh gas flow rates. Adapters for a capnograph are usually attached between the ET tube and breathing circuit and thus may contribute substantially to the apparatus dead space. This may be resolved by attaching a needle to the sampling tube and inserting it directly into the ET tube (sidestream sampling) **(FIGURE 4)**.

If ventilation is required, care must be taken because the small tidal volumes of these patients increase the risk for barotrauma from overzealous ventilation. Airway pressures should not exceed 15 to 20 cm H_2O (10–15 cm H_2O in the open thorax).

Fluid therapy is beneficial to provide hemodynamic support and replace insensible losses; however, it is advisable to use a fluid pump or a syringe pump that will deliver an accurate volume of fluid to decrease the risk of fluid overloading. If neither of these is available, a microdrip set with a burette is an acceptable alternative. Fluid rates should not exceed 10 mL/kg/h (unless in the setting of acute hemorrhage). Maintenance of adequate serum glucose may require fluids containing dextrose, such as 2.5% to 5% dextrose in lactated Ringer's solution. If solutions containing dextrose are not available, glucose can be added to the replacement or maintenance fluids. Regular monitoring of blood glucose while the animal is under anesthesia is advisable.

Temperature probes placed into either the esophagus or rectum should be used and provide a reliable indication of body temperature. Hypothermia should be treated as soon as possible. Patients can begin to lose body temperature once they are premedicated. Many options to conserve body temperature exist. The use of temperature-controlled heating mats (eg, resistive polymer blanket), hot water bottles, or warm air blankets; wrapping extremities; and warming IV and irrigation fluids may all beneficial. Extreme care must be taken to avoid thermal burns, keeping all heating modalities close to body temperature if possible. Airway humidifiers and warmers must be used cautiously in pediatric patients because they may increase apparatus dead space.

Warmed solutions should be used for presurgical skin preparation. Alcohol should only be applied to the animal immediately before surgery because it exacerbates heat loss via evaporation.

Preinduction patient warming is well documented in human patients and is becoming more common in veterinary medicine. Veterinary studies have shown that patients prone to hypothermia, such as pediatric patients, benefit from forced-air warming 20 to 30 minutes before induction. Prewarming decreases the temperature gradient between the body's periphery and core, reducing the heat loss that typically occurs during the first hour of anesthesia[16] **(FIGURE 5)**.

POSTANESTHESIA

As with recovery of any patient, care must be taken to assess the adequacy of respiratory and circulatory function, and support should be provided if necessary.

Hypothermic patients shiver on recovery, which may increase oxygen demands by up to 300%.[17] It is advisable to administer supplemental oxygen to shivering patients to maintain tissue oxygenation. Active warming must be instigated in hypothermic patients.

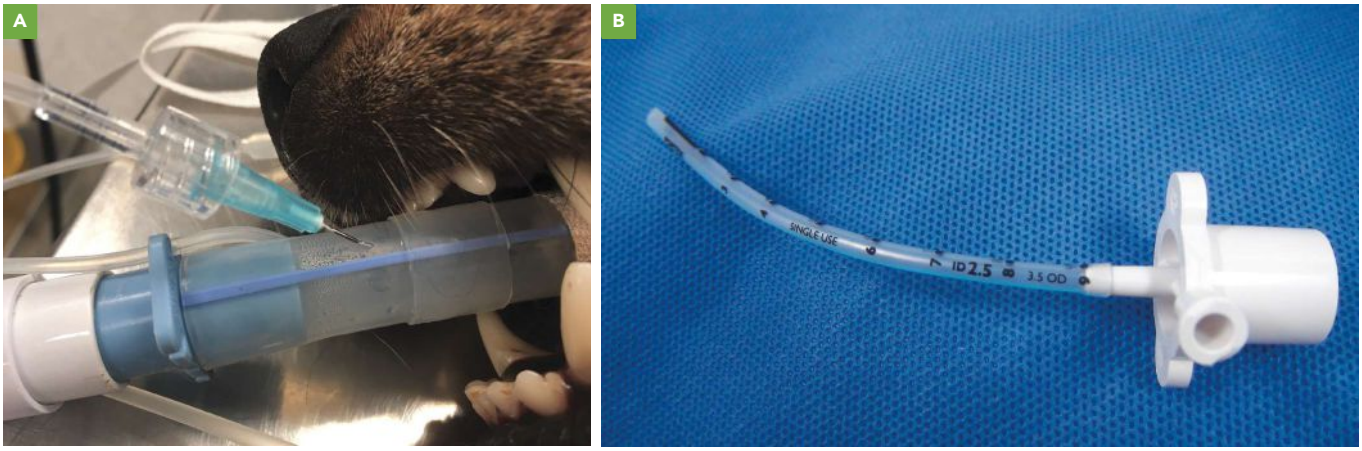

FIGURE 4. To eliminate mechanical dead space from a mainstream adapter, **(A)** a surgical needle may be connected to sidestream sampling tubing and inserted directly into the lumen of the endotracheal tube, or **(B)** an endotracheal tube adapter with a sampling port may be used.

Appropriate analgesia should always be provided by systemic administration of analgesic drugs as well as the use of local blocks, if possible. Pediatric patients may not exhibit overt signs of pain because of survival instincts; thus, recognition of pain can be more challenging. Do not assume that an animal is not in pain because it is exhibiting no obvious signs of pain. Opioid analgesics are good choices, although care must be taken to monitor for adverse effects such as respiratory depression. Therefore, as with all drugs in pediatric patients, doses should be carefully calculated when administered and preferably titrated to effect. Nonsteroidal anti-inflammatory drugs require extensive hepatic metabolism and consequently may not be the most appropriate choice in pediatric patients. Repeated doses should definitely be avoided.

Normal feeding should resume as soon as possible, and unweaned puppies or kittens should be returned to their mothers as soon they are able to suckle.

With adequate preparation and understanding of the unique physiologic and anatomic differences present in pediatric patients, the anesthetist can provide excellent care for these patients. ■

FIGURE 5. Prewarming the pediatric patient using a forced-air warming blanket is beneficial.

TECHPOINT

Capnography provides a measurement of the carbon dioxide content of respiratory gases and therefore is a good indicator of the adequacy of respiratory function.

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