Cesarean Section in Dogs: Anesthetic Management*

Stewart D. Ryan, BVSc (Hons), MACVSc
Ann E. Wagner, DVM, MS, DACVP, DACVA
Colorado State University

ABSTRACT: Cesarean section is common in small animal veterinary practice. Preoperative assessment should include a complete history, a physical examination, a laboratory database, and diagnostic imaging as dictated by a patient’s status. Premedication can decrease maternal stress and anxiety and permits a decrease in the dose of injectable induction drugs and in the minimum alveolar concentration of inhalation anesthetics. Premedication agents that can be reversed (e.g., opioids, benzodiazepines) are preferred. All animals undergoing anesthesia for cesarean section should receive intravenous fluid therapy. Preoxygenation before and during induction significantly decreases the risk of maternal hypoxemia. General anesthesia is preferred over epidural-only anesthesia even though epidural anesthesia has the fewest depressant effects on neonates. Anesthetic protocols that use propofol and isoflurane are associated with decreased maternal and neonatal mortality and increased puppy vigor. Protocols that include α2-agonists, ketamine, or methoxyflurane should be avoided because they have been associated with increased maternal and fetal mortality and decreased neonatal vigor. Monitoring maternal ventilation, arterial oxygenation, blood pressure, and temperature during anesthesia is very important in cesarean section to permit early detection and treatment of adverse changes in these parameters. The importance of tailoring a specific anesthetic protocol to an individual animal is stressed.

The choice of a particular anesthetic protocol should be tailored to the specific animal, taking into account various factors (i.e., condition of the dam and fetuses, the veterinarian’s experience and familiarity with various anesthetic agents and techniques, clinic facilities, personnel available, and an emergency versus elective cesarean presentation). This article covers the perioperative and anesthetic management of cesarean sec-

*A companion article on physiology and perioperative considerations appears on page 34.
tion focused on the reproductive system. Specifically, information on the sequence of events and duration of labor should be obtained via questions including:

- When did signs of first-stage labor start?
- Have any fetal membranes or puppies been visualized at the vulva?
- Have any puppies been delivered? If so, in what condition (i.e., alive, dead, deformed)?
- What was the time interval between puppies that have been delivered?
- What is the previous pregnancy and whelping history, especially regarding dystocia and response to medical or surgical intervention?

General historical information on anesthetic episodes, surgery, illnesses, and medications should also be obtained. Predisposing factors for dystocia (e.g., fetopelvic disproportion, pelvic fracture malunion, hypocalcemia, large litter size) should be assessed.

The physical examination should be thorough and complete but performed in a timely manner as dictated by the condition of the dam. The abdomen should be palpated to assess the size and tone of the uterus in conjunction with a digital vaginal and rectal examination. Vaginoscopy may be indicated if obstructive pathology such as vaginal bands is suspected. Abdominal radiography and/or ultrasonography can be valuable in detecting fetal presence, number, size, and position (Figure 1). Ultrasonography is a more sensitive diagnostic tool for determining fetal viability because radiography cannot differentiate between live and freshly dead fetuses. Ultrasonography can be used to measure fetal movement and heart rates. Fetal heart rates of 150 to 200 bpm indicate a healthy fetus, whereas lower heart rates of 100 to 150 bpm may indicate fetal stress.

Laboratory tests should be conducted as dictated by the patient’s physical status. A packed cell volume as well as total protein, blood urea nitrogen (BUN), calcium, glucose, and electrolyte levels are the recommended minimum laboratory test database that should be obtained before administering anesthesia for cesarean section. Relative anemia and possibly a decreased BUN level may be caused by changes in maternal physiology that occur with pregnancy. Hematocrit values within the normal reference range may actually represent dehydration in late-term pregnant dams. Calcium levels are most likely decreased in small-breed dogs, dogs with large litters, or those diagnosed with uterine inertia. Serum total calcium measurement is an insensitive indicator of calcium homeostasis, so measurement of ionized calcium is preferred. More extensive serum biochemical testing should be conducted as indicated by the clinical status of the dam. Results can help detect acid–base disturbances and direct fluid therapy choices. In an emergency, therapy may need to be initiated before test results are available.

PREMEDICATION

Premedication provides sedation and analgesia for the dam and permits a decreased dose of induction and inhalation anesthetics required for surgery. Premedication reduces anxiety, especially if the dam has already started parturition, has had a prolonged second-stage labor, has delivered pups, or has uterine inertia. Premedication also facilitates placement of an intravenous catheter, allowing fluid therapy and drug delivery before induction of anesthesia. Premedication can have adverse effects on fetuses because most agents can cross the placental barrier; therefore, using short-acting drugs that can be antagonized is preferred.

Opioids provide sedation and analgesia to the dam with minimal cardiac depression but are associated with dose-dependent respiratory depression and bradycardia in both the dam and fetuses. The respiratory depressant effect of opioids can be reversed in the dam and fetuses by administering naloxone. Concurrent administration of an anticholinergic is indicated to increase the heart rate if opioid-induced bradycardia occurs (i.e., a heart rate decrease of 30% or more from resting baseline levels). Atropine (0.01 to 0.02 mg/kg IV or 0.02 to 0.04 mg/kg SC or IM) is preferred over glycopyrrolate for reversing
opioid-induced bradycardia in patients undergoing cesarean section because it crosses the placental barrier, counteracts fetal bradycardia, and has a shorter onset and duration of action than does glycopyrrolate. Glycopyrrolate does not significantly cross the placental barrier because of its large molecular size and ionization. Anticholinergics can also decrease respiratory and gastric secretions.

Benzodiazepines produce skeletal muscle relaxation and mild sedation. They can potentiate respiratory depression associated with opioids. Dose-dependent, prolonged sedation can occur in neonates because the fetal liver does not have mature hepatic enzyme systems with which to metabolize benzodiazepines. This effect can be antagonized with the reversal agent flumazenil in neonates after delivery. Midazolam is water soluble and has a shorter duration of action than does diazepam; thus midazolam is the preferred benzodiazepine for cesarean section. Benzodiazepines can be used intravenously immediately before induction.

Phenothiazine tranquilizers can cause maternal hypotension by α₁-adrenergic blockade and hence lead to fetal hypoxia. Acepromazine has a long duration of action, cannot be reversed, and requires hepatic metabolism. In neonates, acepromazine can cause respiratory depression and decreased ability to thermoregulate; therefore, this drug is not recommended for routine use in patients undergoing cesarean section. One potential indication for acepromazine use is to help facilitate handling, decrease anxiety, and decrease catecholamine release in very anxious, stressed, or aggressive dams. In this instance, acepromazine should be used at very low doses (0.01 to 0.02 mg/kg SC, IM, or IV). α₂-Agonists used in small animal anesthesia (i.e., xylazine, medetomidine) are not recommended in patients undergoing cesarean section because these drugs have been identified as risk factors for increased puppy mortality. Adverse cardiovascular effects include profound bradycardia, potentiation of arrhythmias, decreased myocardial contractility, and initial hypertension followed by hypotension. Bradycardia can be prevented or reversed by administering an anticholinergic, but the other adverse cardiovascular effects cannot be counteracted. An increased heart rate resulting from administration of an anticholinergic, combined with increased afterload from vasoconstriction, results in increased myocardial oxygen demand. Xylazine has an oxytocin-like effect on the uterus and causes maternal and fetal respiratory and cardiovascular depression and possibly premature placental separation at higher doses.

Premedication with metoclopramide or cimetidine has been suggested in some anesthetic protocols to decrease the risk of esophageal reflux and regurgitation. Controlled studies regarding the efficacy of these drugs are lacking in the veterinary literature, but patients undergoing intraabdominal procedures are reported to have an increased risk of passive (“silent”) gastric reflux. Increased gastric acidity and decreased lower esophageal tone secondary to increased abdominal pressure caused

Alterations in maternal respiratory and cardiovascular physiology during pregnancy increase the rapidity of inhalant induction of anesthesia and allow maintenance of anesthesia with a reduced concentration of an inhalation anesthetic.

cesarean section. Benzodiazepines can be used intravenously immediately before induction.

Phenothiazine tranquilizers can cause maternal hypotension by α₁-adrenergic blockade and hence lead to fetal hypoxia. Acepromazine has a long duration of action, cannot be reversed, and requires hepatic metabolism. In neonates, acepromazine can cause respiratory depression and decreased ability to thermoregulate; therefore, this drug is not recommended for routine use in patients undergoing cesarean section. One potential indication for acepromazine use is to help facilitate handling, decrease anxiety, and decrease catecholamine release in very anxious, stressed, or aggressive dams. In this instance, acepromazine should be used at very low doses (0.01 to 0.02 mg/kg SC, IM, or IV).

α₂-Agonists used in small animal anesthesia (i.e., xylazine, medetomidine) are not recommended in patients undergoing cesarean section because these drugs have been identified as risk factors for increased puppy mortality. Adverse cardiovascular effects include profound bradycardia, potentiation of arrhythmias, decreased myocardial contractility, and initial hypertension followed by hypotension. Bradycardia can be prevented or reversed by administering an anticholinergic, but the other adverse cardiovascular effects cannot be counteracted. An increased heart rate resulting from administration of an anticholinergic, combined with increased afterload from vasoconstriction, results in increased myocardial oxygen demand. Xylazine has an oxytocin-like effect on the uterus and causes maternal and fetal respiratory and cardiovascular depression and possibly premature placental separation at higher doses.

Premedication with metoclopramide or cimetidine has been suggested in some anesthetic protocols to decrease the risk of esophageal reflux and regurgitation. Controlled studies regarding the efficacy of these drugs are lacking in the veterinary literature, but patients undergoing intraabdominal procedures are reported to have an increased risk of passive (“silent”) gastric reflux. Increased gastric acidity and decreased lower esophageal tone secondary to increased abdominal pressure caused

INTRAVENOUS FLUID THERAPY

 Intravenous fluid therapy is strongly recommended for all dogs undergoing cesarean section. In a recent survey, however, intravenous fluid therapy was administered only 53% of the time for cesarean section. Fluid therapy should begin preoperatively, and fluid deficits and electrolyte or acid–base imbalances should ideally be corrected before surgery. Fluid therapy with crystalloids helps counteract the hypertensive effects of anesthetics and maintain cardiac output and uterine blood flow. Selection of crystalloid versus colloid fluid and the
need for additives are based on clinical parameters and laboratory test results. The crystalloid of choice is lactated Ringer’s solution administered at an initial rate of 10 to 20 ml/kg/hr. Higher rates of administration are used if hypotension or hypovolemia are encountered. Intravenous fluids should be warmed to body temperature to minimize the chance of inducing or potentiating preexisting maternal hypothermia.

Colloid solutions (e.g., hetastarch, dextran 70, blood products) remain in the vascular space longer than crystalloids and may be useful for refractory hypotension. Blood transfusion with whole blood or packed red blood cells may be required if blood loss is severe; thus, ideally, dogs should be blood-typed and fresh blood should be available if severe hemorrhage is anticipated.

**PREOXYGENATION**

Dogs in late pregnancy are more prone to hypoxemia because of decreased functional reserve capacity and increased metabolic rate. Maternal hypoxemia can lead to fetal hypoxia and acidosis. Animals are most susceptible to hypoxemia during anesthetic induction, when transient apnea frequently occurs because of an anesthetic induction agent. It is strongly recommended to preoxygenate the dam with 100% oxygen by face mask for 5 minutes (4 to 6 L/min) before and during induction of general anesthesia until an endotracheal tube is placed. Premedication decreases the potential stress of face-mask oxygenation (Figure 2).

**REGIONAL AND LOCAL ANESTHETIC TECHNIQUES**

Epidural anesthesia can be used as the sole anesthetic method to successfully perform cesarean section in dogs. The technique of epidural injection has been well described. Epidurally administered lidocaine provides good regional anesthesia and abdominal muscle relaxation. Epidural lidocaine (2%; 2 to 3 mg/kg to a maximum of 6 ml) is preferred over bupivacaine for cesarean section because it has a shorter onset of action (i.e., 5 to 10 minutes) and duration of action (i.e., 60 to 90 minutes), which is an appropriate duration for most cesarean sections. Analgesics (e.g., morphine) can be administered epidurally in combination with local anesthetics to provide analgesia as well as anesthesia. The volume of an epidural anesthetic should be reduced by 25% to 35% (compared with the volume that would be used in a nonpregnant animal) because of decreased epidural and cerebrospinal fluid spaces secondary to epidural venous distention resulting from increased collateral circulation. Heavy sedation may be required to administer the epidural anesthetic and help restrain the dam. Assistants are required to manually restrain patients that are still conscious and may respond to noises. To facilitate closure of the uterus and body wall, inhalation anesthesia can be administered to the dam after delivery of the puppies.

Hypotension caused by sympathetic blockade with resulting vasodilation is one of the main complications of epidural anesthesia. Therefore, blood pressure monitoring is important when epidural anesthesia is used. Hypotension associated with epidural anesthesia should be treated with intravenous fluid boluses but may be refractory and require treatment with pressors. Preemptive fluid loading is recommended to minimize this potential complication.

With epidural anesthesia, the dam is not endotracheally intubated; thus supplemental oxygen can be administered only by face mask or nasal insufflation, and regurgitated material is more likely to be aspirated. Prolonged blockade may occasionally cause postoperative hindlimb paralysis and urinary retention.

Epidural anesthesia is an accepted technique for cesarean section, with the main advantage over general anesthesia being minimal fetal exposure to anesthetics, allowing pups to be more vigorous at birth. The disadvantages of epidural anesthesia include the frequent need for sedation and a lack of airway protection. With the introduction of newer injectable and inhalation anesthetics and balanced anesthesia techniques, using epidural
anesthesia as the sole means of anesthesia for surgical procedures in small animals has become less popular.

**GENERAL ANESTHESIA TECHNIQUES**

**Induction**

A short time between induction and delivery of neonates is desirable, but a very short time has not been shown to have a beneficial effect on puppy survival. If the abdomen has been clipped in the preparation area, induction can be done in the operating room. This decreases the time from induction to delivery and prevents the need for patient repositioning and transportation after induction. The aim of using any induction agent is to provide rapid transfer to unconsciousness and allow endotracheal intubation for airway protection and ventilatory support with high inspired oxygen concentrations.

Inhalation induction can be achieved via a mask or chamber. Using nitrous oxide and inhalation agents with a lower solubility (e.g., desflurane, sevoflurane, isoflurane) makes induction more rapid. Inhalation induction of anesthesia is more rapid in pregnant animals because of decreased functional reserve capacity and increased minute volume, permitting rapid equilibration between inspired and alveolar anesthetic concentrations.

Disadvantages of inhalation induction are stress and hypoxemia in the dam, leading to catecholamine release, maternal hypoxia, and fetal hypoxia and acidosis. Inhalation induction takes longer than injectable induction, and the risk of regurgitation and aspiration is higher because the airway is unprotected. Because of these concerns, we recommend using an injectable induction technique over inhalation induction for patients undergoing cesarean section. Induction with rapidly acting injectables facilitates endotracheal intubation, which protects the airway and allows assisted ventilation.

Propofol is a rapid, ultra–short-acting nonbarbiturate injectable induction agent with induction and recovery characteristics similar to those of thiopental. The reported induction dose for propofol is 6 to 8 mg/kg IV in dogs that have not been premedicated; premedication may reduce this induction dose by 25% to 70% (i.e., 2 to 5 mg/kg IV). Propofol is metabolized in the liver and readily crosses the placenta, reaching the fetal circula-

tion. Propofol can cause hypotension as a result of arteriolar vasodilation; because this is more severe in dogs that have preexisting hypovolemia, an intravenous fluid bolus (i.e., 5 to 10 ml/kg) should be administered to the dam before induction. Hypotension caused by propofol does not result in a baroreceptor-mediated heart rate increase, so bradycardia may occur and should be treated with anticholinergic administration.

Because transient dose- and rate-dependent apnea and respiratory depression are common with propofol use, assisted ventilation in the immediate induction period may be required. Large, rapid boluses are associated with more severe respiratory depression. Propofol does not provide analgesia, so additional means of analgesia, such as opioid premedication, should be provided. Propofol can be used as a sole maintenance agent via either constant-rate infusion (CRI) or repeat boluses. Unlike thiopental, repeated boluses of propofol do not have a cumulative effect on the dam but may be associated with more severe neonatal respiratory depression. Because of the pharmacokinetic properties of propofol, it is considered the induction agent of choice for cesarean section anesthesia by many anesthesiologists.

Thiopental is a rapid-acting thiobarbiturate induction agent that is an alternative to propofol. One-quarter of the reported premedicated induction dose (i.e., one-quarter of 5 to 10 mg/kg) should be rapidly administered intravenously and then additional drug titrated to effect. Cardiovascular and respiratory depressant effects are produced in fetuses as well as the dam. Fetal depression is minimized when the lowest possible induction dose is used. Use of thiopental is associated with decreased puppy vigor at birth, but not with decreased puppy survivability. Propofol is our recommended injectable induction agent of choice.

After administration of a short-acting injectable induction agent (e.g., propofol, thiopental), 15 to 20 minutes should be allowed to elapse before delivery of neonates to allow drug metabolism and redistribution and significantly reduce respiratory depression of neonates.

Ketamine (4 to 6 mg/kg IV) combined with diazepam (0.2 to 0.4 mg/kg IV) or midazolam (0.1 to 0.3 mg/kg IV) can be used in critically ill dams. Ketamine causes...
less cardiovascular depression in dams than does propofol or thiopental but may have significant depressant effects in neonates. The use of ketamine is associated with a decreased likelihood of all pups breathing spontaneously at birth and greater neonatal depression compared with the use of other induction agents.18,28

Etomidate (1 to 2 mg/kg IV) is the induction agent of choice for severely compromised dams or those with pre-existing cardiac disease.29,30 It produces hypnosis and provides rapid induction with minimal cardiovascular and respiratory depressant effects and has a short duration of action. Studies in pregnant women showed that etomidate is incompletely transferred to the fetus and the fetal plasma concentration of etomidate decreases rapidly.31 Etomidate administration can be preceded with a benzodiazepine (e.g., midazolam) to reduce potential excitatory side effects.30 Etomidate may cause irritation during intravenous injection because of hypertonicity, so it is recommended that the agent be diluted to a ratio of 50:50 with 0.9% saline. Etomidate is significantly more expensive than other induction agents.

Fentanyl is a short-acting opioid with potent analgesic properties that provides heavy sedation and analgesia. The dose for profound sedation is 10 µg/kg IV. Many dogs can be intubated after administration of this dose of fentanyl in combination with either diazepam or midazolam (0.2 mg/kg IV). Fentanyl is associated with minimal maternal cardiovascular depression but can cause respiratory depression and bradycardia that is reversible with anticholinergic administration. The depressant effects of fentanyl can be reversed in neonates by administering naloxone. When fentanyl is used in combination with other induction agents (e.g., propofol, thiopentone), the dose of these agents is typically markedly reduced. Fentanyl can also be used as a CRI (5 to 40 µg/kg/hr) after induction in combination with inhalation anesthesia to produce a dose-dependent reduction of up to 60% to 70% in minimum alveolar concentration (MAC).19 Adding a CRI opioid also provides another source of analgesia. If a CRI opioid is used, the infusion should be stopped approximately 30 minutes before the end of the procedure to expedite anesthetic recovery without respiratory depression.

As indicated previously, benzodiazepines (i.e., midazolam, diazepam) can be used in combination with other induction agents to significantly decrease the dose of these induction agents. There is potential for more severe depressant effects in neonates because of their immature hepatic enzyme development. Adverse effects can be reversed by administering flumazenil (0.1 mg/kg IV).

**Maintaining Anesthesia**

Using inhalation anesthesia with a cuffed endotracheal tube allows delivery of higher concentrations of inspired oxygen and controlled or assisted ventilation, if required. All inhalation anesthetics cross the placenta because of their lipid solubility and low molecular weight. Volatile inhalation agents cause potent cardiovascular and respiratory depression.19 The delivery of inhalation anesthetics should be titrated to effect and the delivered concentration kept as low as possible to avoid anesthetic overdose and minimize neonatal respiratory depression.28 Neonates rapidly eliminate inhalation anesthetics once spontaneous respiration commences.28

The MAC of inhalation anesthetics in humans and animals is decreased during pregnancy by 25% for halothane and 28% to 40% for isoflurane.12,13 If mechanical or assisted ventilation is used during anesthesia, care must be taken to avoid maternal hyper-ventilation, which can lead to severe maternal hypocapnia (partial pressure of carbon dioxide <32 mm Hg) and an associated decrease in uterine and umbilical blood flow and increased maternal oxygen affinity for hemoglobin.1 These conditions lead to decreased oxygen delivery to fetuses and fetal hypoxemia.34 If the dam is breathing spontaneously and not being mechanically ventilated during anesthesia, intermittent “sigh” breaths are recommended to help maintain good maternal ventilation by preventing pulmonary atelectasis.1

Halothane, isoflurane, sevoflurane, and desflurane can be used as maintenance inhalation anesthetics. Isoflurane use is associated with increased neonatal survival compared with halothane or methoxyflurane use6 and is preferred over halothane for emergency cesarean section.1 Desflurane and sevoflurane have not been specifically evaluated in veterinary cesarean section anesthesia.
but have cardiopulmonary depressant effects similar to those of isoflurane. Methoxyflurane should be avoided as a maintenance inhalation agent because it has been associated with decreased puppy survival. Nitrous oxide should not be used for cesarean section or should be used only to expedite inhalant induction and terminated once the dam has been intubated. Nitrous oxide decreases the maternal inspired oxygen concentration and can cause diffusion hypoxia in neonates.

A study by Moon and colleagues found that the two most common anesthetic protocols were induction and maintenance with isoflurane (34%) and propofol induction followed by isoflurane for maintenance (30%). The use of isoflurane and/or propofol was associated with a lower puppy mortality rate, and the use of xylazine or methoxyflurane was associated with an increased puppy mortality rate. The use of thiobarbiturate, ketamine, or inhalation anesthetics was associated with decreased puppy vigor, but not increased puppy mortality. Results of a study by Funkquist et al support the use of propofol–isoflurane anesthesia as a superior general anesthesia protocol over induction with thiopental sodium and maintenance with isoflurane. In another recent study, propofol was the safest induction agent, followed by thiopental and then midazolam–ketamine.

Because no anesthetic protocol is suitable for every cesarean section, protocols should be tailored to the individual animal. Anesthetic protocols should be tailored to the individual animal.

No single anesthetic protocol is suitable for every cesarean section. Anesthetic protocols should be tailored to the individual animal.

Blood pressure can be measured by direct or indirect techniques. Direct blood pressure monitoring using an arterial catheter and aneroid manometer or strain gauge transducer is the gold standard and provides the most accurate information on blood pressure status, giving systolic, diastolic, and mean blood pressure readings. It provides continuous information and accurate readings in hypo-, normo-, and hypertensive states. Arterial catheter placement also allows serial arterial blood sampling for blood gas analysis—the gold standard for assessing ventilation. Placing an arterial catheter can be technically demanding and time-consuming and can delay delivery of puppies; therefore, invasive blood pressure monitoring is not routinely recommended for cesarean section. Noninvasive blood pressure monitoring using a Doppler flow detector and sphygmomanometer is an easy, inexpensive method, providing an acceptable estimate of the systolic arterial pressure in dogs. No information about diastolic or mean blood pressures can be gained with the Doppler method. The noninvasive osilometric technique provides an automatic readout of systolic, mean, and diastolic blood pressures as well as pulse rate. There is a good correlation between osilometric and direct arterial pressure measurements in hypo-, normo-, and hypertensive states unless vasoconstriction or brady-
The main disadvantages of the noninvasive osillometric technique are that it is more expensive than the Doppler method and readings may be unreliable in very small animals.

Hypotension is a common complication in anesthetized patients, resulting from the cardiac depressant effects of anesthetics, particularly inhalation agents. Hypotension can be significant during cesarean section because hemorrhage and increased intraabdominal pressure decrease cardiac return. Hypotension that requires treatment during anesthesia is defined as mean arterial pressure below 60 mm Hg and/or systolic arterial pressure below 80 mm Hg. Initial treatment involves decreasing the depth of anesthesia and administering a crystalloid fluid bolus (5 to 10 mg/kg IV). If crystal-
loid therapy is ineffective, synthetic colloids such as hetastarch can be given as a 5 ml/kg IV bolus rather than repeated crystalloid boluses, which risk hemodilution and pulmonary overload. Opioids produce fewer cardiovascular-depressant effects than do inhalation anesthetics and can be administered via intravenous bolus (e.g., fentanyl at 2 µg/kg) or CRI (e.g., 5 to 20 µg/kg/hr) to decrease the concentration of inhalation anesthetics administered, possibly resulting in improved blood pressure and tissue perfusion.41 If bradycardia is present, anticholinergics (i.e., atropine, glycopyrrolate) can be given to increase the heart rate and improve cardiac output. If these measures do not improve blood pressure, inotropes are indicated to improve cardiac contractility, cardiac output, and blood pressure.

Dobutamine causes increased cardiac contractility due to β1 effects and results in increased cardiac output, stroke volume, and mean arterial blood pressure. It is used for refractory hypotension at a CRI of 1 to 5 µg/kg/min.

Dopamine at low doses (i.e., <4 µg/kg/min) preferentially activates dopaminergic receptors, dilating the splanchnic and renal vasculature and thereby increasing renal blood flow and the glomerular filtration rate. At doses of 4 to 10 µg/kg/min, β1-receptors are stimulated, resulting in improved cardiac contractility as well as increased heart rate, cardiac output, and blood pressure. At doses greater than 10 µg/kg/min, α1-receptor activity leads to vasoconstriction and increased systemic vascular resistance, potentially decreasing blood flow to the uterus.

Ephedrine (0.1 to 0.25 mg/kg IV) can be administered as a bolus because it has a longer half-life than dopamine, dobutamine, or epinephrine.1,34,40 Epinephrine is a potent α1- and β1-agonist and a moderate β2-agonist. At CRI rates of 0.04 to 0.1 µg/kg/min, β effects predominate, resulting in increased heart rate and contractility, with unchanged or decreased peripheral resistance. At higher doses, α effects predominate, resulting in increased peripheral vascular resistance and blood pressure. Epinephrine dramatically reduces uterine blood flow and should be used only in life-threatening situations when other efforts to correct hypotension have failed1 (see box on this page).

Respiratory Monitoring
Arterial blood gas analysis is the gold standard for assessing ventilation, arterial oxygenation, and acid–base
status. The technique for arterial sampling and interpretation is well described.\textsuperscript{41}

Capnography can be used to assess ventilation by measuring the end-tidal carbon dioxide concentration, which approximates the alveolar carbon dioxide concentration, which should in turn approximate the partial pressure of arterial carbon dioxide (PaCO\textsubscript{2}). The value displayed on the capnograph can be interpreted as the lowest value for PaCO\textsubscript{2}, but true values of PaCO\textsubscript{2} may be higher than the displayed values. If the PaCO\textsubscript{2} is greater than 55 mm Hg, commercially available capnometers tend to underestimate the PaCO\textsubscript{2} by as much as 20 mm Hg.\textsuperscript{42} Capnography is best used as a trend analysis tool and does not replace arterial blood gas analysis as the best method of assessing adequacy of ventilation.

Pulse oximetry provides a simple noninvasive means of monitoring arterial oxyhemoglobin saturation (SpO\textsubscript{2}) of the dam during anesthesia. It also provides information on the pulse (heart) rate. The relationship between SpO\textsubscript{2} and arterial blood gas measurements of PaO\textsubscript{2} is not linear. Most animals remain sufficiently oxygenated as long as SpO\textsubscript{2} is 90% or greater, corresponding to a PaO\textsubscript{2} of greater than 60 mm Hg. SpO\textsubscript{2} measurements are best used as a real-time trend indicator of arterial oxyhemoglobin saturation during surgery but do not replace arterial blood gas analysis as the gold standard of assessing arterial oxygenation. A hematocrit of greater than 15% is required for accurate pulse oximeter readings in dogs.\textsuperscript{43}

Respiration can be monitored by direct observation of thoracic wall movement and subjective assessment of breathing bag excursions. Electronic respiratory monitors can also be used as additional aids but do not replace the need for direct monitoring of respiration and do not provide information about the effectiveness of ventilation.\textsuperscript{44}

**Temperature Monitoring**

Maternal hypothermia can be significant with cesarean section. Core body temperature should be monitored with an esophageal or rectal probe. Methods of supporting body temperature include heated operating tables, warmed intravenous and abdominal lavage fluids, radiant heat lamps, and circulating warm-air blankets.

**SUMMARY**

Understanding the changes in maternal and fetal physiology that occur during pregnancy and the pharmacokinetics and pharmacodynamics of anesthetics is necessary to formulate an effective and safe anesthetic plan for pregnant dogs. No single anesthetic protocol is
suitable for every cesarean section. All patients undergoing cesarean section should be administered intravenous fluids. Preoxygenation of the dam for 5 minutes before and during induction until endotracheal intubation is strongly recommended to decrease the risk of hypoxemia. Premedications that can be specifically antagonized (e.g., opioids, benzodiazepines) are preferred so that depressant effects in neonates can be reversed. Anesthetic protocols that include propofol and isoflurane are associated with decreased maternal mortality and increased neonatal survival and vigor. Xylazine, ketamine, and methoxyflurane should be avoided as anesthesia for cesarean section because they have been identified as risk factors for increased neonatal or maternal mortality and are associated with decreased neonatal vigor. Selection of appropriate anesthetics and good perioperative management minimize the risks to the dam and puppies, help decrease maternal and neonatal mortality, and increase neonatal vigor.

REFERENCES

ARTICLE #3 CE TEST

This article qualifies for 2 contact hours of continuing education credit from the Auburn University College of Veterinary Medicine. Subscribers may purchase individual CE tests or sign up for our annual CE program. Those who wish to apply this credit to fulfill state relicensure requirements should consult their respective state authorities regarding the applicability of this program. To participate, fill out the test form inserted at the end of this issue or take CE tests online and get real-time scores at CompendiumVet.com.

1. A fetal heart rate of 150 to 200 bpm indicates
   a. fetal tachycardia.  c. fetal stress.
   b. a healthy fetus.  d. none of the above

2. Which statement regarding premedication and perioperative management is false?
   a. Opioid and benzodiazepine premedications can be specifically antagonized in neonates.
   b. \( \alpha_2 \)-Agonists (e.g., xylazine) are not recommended for cesarean section.
   c. Intravenous fluid therapy is recommended for all patients undergoing cesarean section.
   d. Premedication has no adverse effects on fetuses.

3. Which statement regarding perioperative management is false?
   a. A minimum laboratory database for patients undergoing cesarean section should include packed cell volume as well as total protein, glucose, BUN, electrolyte, and calcium levels.
   b. Patients should be preoxygenated with 100% oxygen for 5 minutes before and during induction of anesthesia.
   c. Patients undergoing intraabdominal procedures, such as cesarean section, are at increased risk of passive gastric reflux.
   d. Preoperative abdominal radiography is a reliable indicator of fetal viability.

4. Which statement regarding epidural anesthesia for cesarean section is false?
   a. Epidural anesthesia can be used as the sole method of anesthesia for cesarean section.
   b. Epidural anesthesia can be associated with maternal hypotension.
   c. The dam's airway is protected so that reflux esophagitis is not a concern.
   d. Fetal exposure to anesthetics is minimized so that neonates are more vigorous at birth compared with general anesthesia techniques.
5. Which injectable induction agent is associated with increased neonatal viability and vigor?
   a. propofol  c. medetomidine  
   b. ketamine  d. thiopental

6. Which maintenance inhalation agent is associated with decreased puppy survival?
   a. halothane  c. methoxyflurane 
   b. isoflurane  d. sevoflurane

7. Which statement regarding anesthetic use is false?
   a. Propofol induction can be associated with transient apnea and hypotension.
   b. Using balanced anesthetic techniques lowers the MAC of inhalation anesthetic required to maintain anesthesia.
   c. Inhalation induction is safer than intravenous induction.
   d. Ketamine induction is associated with a decreased likelihood of puppies breathing spontaneously at birth.

8. Which statement regarding anesthetic management for cesarean section is false?
   a. Because maternal hypothermia can be significant during cesarean section, appropriate methods to support body temperature should be used.
   b. Preoxygenation with 100% oxygen by face mask is recommended for 5 minutes at 4 to 6 L/min before and during induction.
   c. Xylazine, ketamine, or methoxyflurane is safe and appropriate to use in cesarean section anesthesia protocols.
   d. Initial treatment of hypotension involves decreasing the depth of anesthesia and administering an intravenous fluid bolus.

9. Which statement regarding anesthetic monitoring is true?
   a. Direct arterial blood pressure monitoring is recommended for all cesarean patients.
   b. Pulse quality and magnitude are direct indicators of cardiac output and blood pressure.
   c. Pulse oximeters provide a pulse rate reading and measure $\text{SpO}_2$.
   d. Capnography is a direct measurement of $\text{PaCO}_2$.

10. Mild maternal hypotension during cesarean section should initially be treated
    a. with a CRI of dobutamine.
    b. by reversing narcotic premedication agents.
    c. with a bolus of intravenous epinephrine.
    d. by decreasing the depth of anesthesia and increasing the rate of fluid administration.

Test answers now available at CompendiumVet.com