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Anesthetic protocols for canine cesarean section: a literature review

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Introduction

Cesarean sections in dogs are a critical intervention employed to safeguard the health of both mother and offspring during complications of pregnancy and parturition. Ensuring optimal anesthesia during these procedures is paramount to mitigating risks and ensuring successful outcomes. Over the years, veterinary anesthesiologists have refined protocols to cater specifically to the physiological demands of pregnant dogs undergoing cesarean sections. Considerations must be made for the physiological adaptations occurring in the mother during pregnancy, alongside the unique pharmacokinetic and pharmacodynamics responses of drugs in both the fetus and the mother. The primary objective of a cesarean section is to safeguard the vitality of the puppies and ensure the well-being of the mother, achieved through safe anesthesia during the procedure and prompt recovery of consciousness afterward. Numerous anesthetic protocols have been developed since the 1990s, reflecting advancements in research and the evolution of various drugs, with careful consideration of their potential side effects. This literature review explores the evolution of anesthetic protocols in this context, from historical perspectives to current practices, aiming to elucidate trends, challenges, and advancements in veterinary anesthesia for cesarean sections.

Cesarean sections in veterinary medicine serve as a crucial method for managing dystocia, fetal distress, or maternal health complications, where conventional delivery methods are not feasible or safe. Maternal mortality rates associated with cesarean sections have significantly decreased over the past 40 years, dropping from 13% to 1%[1]. Anesthesia plays a pivotal role in these surgeries by providing pain relief, muscle relaxation, and maintaining physiological stability throughout the procedure. The unique physiological changes in pregnant dogs necessitate tailored anesthetic approaches to minimize risks such as hypotension, hypoventilation, and fetal compromise.

This literature review aims to explore the spectrum of anesthetic agents and techniques utilized in cesarean sections for dogs, taking into account the physiological changes in maternal and fetal physiology during pregnancy, as well as post-operative considerations. It aims to delve into the historical development of protocols, current guidelines and recommendations, factors influencing protocol selection, and emerging trends in veterinary anesthesia. By synthesizing existing literature, this review aims to provide a consolidated overview of best practices and highlight areas requiring further research and refinement.

The primary goal of this review is to critically analyze the evolution of anesthetic protocols for cesarean sections in dogs, with a focus on their efficacy, safety, and impact on maternal-fetal outcomes. This includes considerations such as neonatal resuscitation and post-operative care of the dam, informed by a comprehensive understanding of maternal and fetal physiology. Additionally, it seeks to identify gaps in current knowledge and propose avenues for future research aimed at optimizing anesthesia management in this specialized field of veterinary medicine.

Understanding and refining anesthetic protocols for cesarean sections in dogs holds significant implications for veterinary clinical practice and animal welfare. By enhancing our knowledge base, veterinarians can improve perioperative care, minimize complications, and ultimately enhance outcomes for both canine patients and their offspring.

This review is structured into several sections: firstly, it explores maternal and fetal physiology, neonatal resuscitation, and post-operative care of the dam. Following this, it discusses anesthesia drugs, their evolution of use, and adherence to current guidelines and protocols. It concludes by highlighting the evolution of the anesthetic protocol and current recommendations.

Maternal Physiology

During pregnancy, both dams and fetuses experience an increased metabolic demand. To accommodate this, maternal blood volume increases progressively by about 40% [1]. This physiological expansion of plasma volume outpacing the increase in red blood cells production cause hemodilution and relative anemia. This normochromic, normocytic anemia starts developing between days 25 and 30 of pregnancy and is most pronounced at full term, with hematocrit values dropping to as low as 30% to 35%. The severity of anemia tends to be greater with a higher number of fetuses. A rightward shift in the hemoglobin dissociation curve ensures that even at lower partial pressures of oxygen (such as those found in the placental environment), hemoglobin releases oxygen effectively. This benefits maternal oxygenation and supports the metabolic demands associated with pregnancy. The increased blood volume during pregnancy is matched by a proportional increase in cardiac output, driven by higher heart rate and stroke volume. Peripheral vascular resistance decreases due to the expanded capacity of blood vessels in

the uterus, mammary glands, kidneys, striated muscle, and skin. This adaptation helps maintain mean arterial blood pressure and prevents circulatory overload despite the increased cardiac output. However, the compensatory cardiovascular baroreceptor mechanisms, which respond to hemorrhage or hypotension, may be less effective during pregnancy. As a consequence, the heart has to work harder, and its ability to cope with additional stress is reduced. Animals with existing heart conditions that were stable or well-managed with medication before pregnancy may struggle and could develop heart failure during pregnancy and parturition.

During pregnancy, several changes occur in respiratory physiology to accommodate the increased metabolic demands of the mother and fetus. For instance, there is a decrease in functional residual capacity (FRC) and total lung volume. This is due to an enlarging uterus, displacing the diaphragm upwards and compressing the lungs. The mechanical effect reduces the FRC and the total lung volume because the lungs have less space to expand fully during inhalation. Minute ventilation and oxygen consumption on the contrary are increased to meet the metabolic demands of the fetus, uterus, and mammary glands. This combination of decreased FRC and increased oxygen consumption makes dogs in late gestation highly susceptible to hypoxemia. Any period of apnea can quickly lead to maternal arterial hemoglobin desaturation, reduced oxygen delivery to the fetus, and consequently, fetal hypoxia. Pre-oxygenation with 3 to 5 L/min of 100% oxygen via a face mask before and during anesthesia induction is crucial to mitigate the risk of hypoxemia, particularly during the critical period of apnea at induction.

Additionally, the arterial partial pressure of carbon dioxide (PaCO2) typically decreases due to heightened sensitivity of the respiratory center in the brainstem. This increased sensitivity leads to a higher level of responsiveness to carbon dioxide levels, resulting in an overall increase in minute ventilation. The normal PaCO2 in pregnant animals can be as low as 30 to 33 mmHg, compared to 40 mmHg in non-pregnant animals.

Hyperventilation, whether spontaneous (as may occur due to stress, anxiety, or pain during labor) or induced by assisted ventilation under general anesthesia, can exacerbate maternal hypocapnia. In conditions of hypocapnia, the maternal oxyhemoglobin dissociation curve shifts to the left, increasing maternal hemoglobin's affinity for oxygen (Bohr effect) and thereby reducing oxygen transfer to the fetus.

Decreased functional residual capacity (FRC) and increased minute ventilation in pregnant animals facilitate rapid equilibration between inspired and alveolar inhalant

anesthetic concentrations, resulting in faster induction of inhalation anesthesia compared to non-pregnant animals. The exact mechanism for this heightened sensitivity is unclear, but it is believed to be related to increased serum progesterone concentrations exerting a depressant effect on the central nervous system (CNS) [1]. Consequently, pregnant animals may be at higher risk of relative anesthetic overdose.

During pregnancy, the kidneys receive more blood and filter it faster because of increased blood volume and heart output. This lowers levels of serum urea nitrogen and creatinine compared to dogs that are not pregnant. Also, insulin resistance may happen because progesterone makes the mammary glands produce more growth hormone. This can make pregnant dogs with diabetes less responsive to insulin treatment and cause high blood sugar in healthy pregnant dogs.

Dogs undergoing intra-abdominal procedures face an increased risk of silent regurgitation during anesthesia. In pregnant animals, increased gastric acidity and elevated intra-abdominal pressure due to the gravid uterus reduce gastric and lower esophageal sphincter tone, making regurgitation, and the potential for aspiration or esophagitis, more likely. While a prospective study found that five out of nine dams that died had evidence of pneumonia [2], a definitive link to regurgitation or aspiration was not confirmed. Additionally, on the contrary of large ruminants [3], there are no specific studies comparing the risk of regurgitation and aspiration in late-pregnant dogs to non-pregnant dogs undergoing anesthesia.

Fetal Physiology

Anesthesia is of considerable importance taking into account that drugs that can cross the blood-brain barrier can also cross the placental barrier. Since all anesthetic and sedative drugs cross the blood-brain barrier to produce their effects on the central nervous system, they likewise cross the placenta and impact the fetus.

Dogs possess endotheliochorial placentation where the chorionic epithelium of the placenta comes into direct contact with the endothelium of the maternal blood vessels. This type of placentation involves fewer tissue layers between maternal and fetal blood supplies compared to other types such as epitheliochorial placentation. This configuration facilitates more efficient transfer or nutrients, gases and other substances such as drugs. The extensive zonular implantation areas provides a large surface for exchange between

maternal and fetal blood, facilitating furthermore the transfer of drugs from maternal to fetal circulation via simple diffusion. Most anesthetics exhibit characteristics such as low protein binding, low molecular weight, high lipid solubility, and poor ionization, which enhance their ability to cross the placental barrier and affect the fetus.

Fetal circulation differs significantly from adult circulation (*Figure.1*), with oxygenated blood from the placenta entering the fetus through the umbilical vein towards the liver. The umbilical vein has a low partial pressure of oxygen (PO2), around 40 mmHg, so to efficiently utilize this blood, fetal hemoglobin has a higher affinity for oxygen compared to maternal hemoglobin. There is a leftward shift in the fetal oxyhemoglobin dissociation curve illustrating it. A significant portion of this blood bypasses the liver entering the caudal vena cava and mixing with venous blood. Consequently, the PO2 of fetal blood returning to the right atrium is about 25 mmHg, indicating a state of relative hypoxemia compared to maternal levels. The relevant information to retain is that maternal hypoxemia can precipitate fetal hypoxia and acidosis.

Anesthetics that enter fetal circulation are partially metabolized by the fetal liver and diluted with blood from the caudal circulation before reaching the fetal heart and brain. This ensures relative protection of the fetal heart and brain from high concentrations of anesthetics. Anesthetics with short half-lives cause transient peak concentrations, which means their effects on both the mother and fetus are brief and less likely to cause prolonged depression. On the contrary, those administered continuously, such as volatile inhalation agents or constant-rate infusion injectable, may cause persistent depressant effects. Volatile inhalation anesthetics are known to significantly depress cardiovascular function (e.g., reducing heart rate and blood pressure) and respiratory function (e.g., decreasing respiratory rate and tidal volume). The selection of inhalation anesthetics with low blood solubility and maintaining the lowest possible gaseous anesthetic concentrations are recommended to minimize neonatal depression.

The hepatic microsomal enzyme systems responsible for drug metabolism are underdeveloped or absent in neonatal puppies, requiring 3 to 5 weeks to reach adult levels [4]. Consequently, drugs undergoing hepatic metabolism have a prolonged duration of effect in fetuses or neonates.

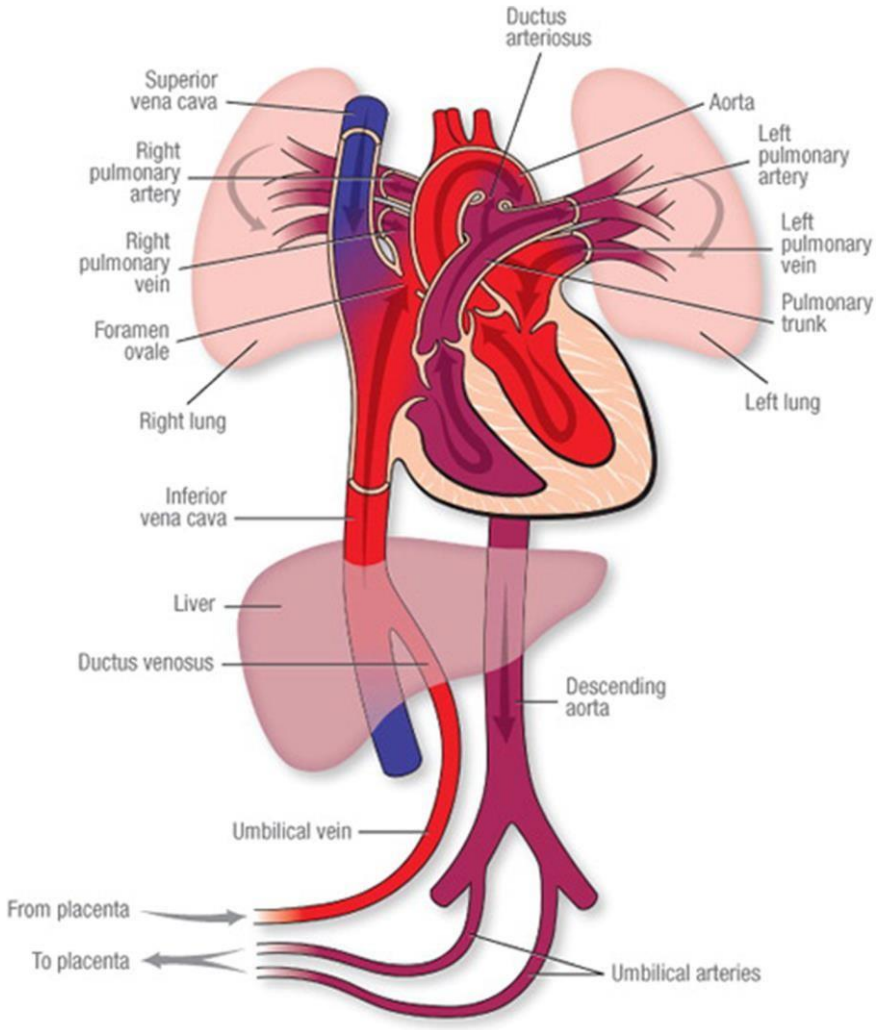

Figure 1. Schematic drawing of fetal circulation [5]

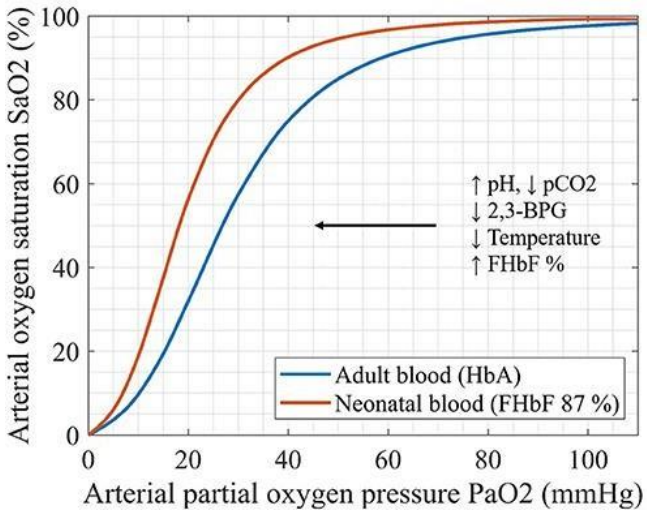

Figure 2. Oxyhemoglobin dissociation curves (ODC) of adult and neonatal blood sample [6]

Table 1 summarizes maternal and fetal physiologic changes that occur during pregnancy and their clinical implications [4].

Physiologic change	Clinical Implication
Maternal • Increased blood volume (by 40% at term) • Relative anemia (packed cell volume = 30%-35% at term) • Increased cardiac output (increased heart rate and stroke volume) • Decreased peripheral vascular resistance • Insulin resistance (progesterone mediated) • Decreased functional residual capacity and lung volume • Increased oxygen consumption, • Increased minute volume and alveolar ventilation • Increased progesterone level • Decreased $PaCO_2$	• Decreased volume of epidural drugs required • Increased cardiac work • Decreased cardiac reserve • Hypotension • Hyperglycemia • Increased likelihood of hypoxemia (especially at induction) • More rapid anesthetic induction • Lower minimum alveolar concentration required for maintenance • Hyperventilation may cause fetal hypoxemia
Fetal • Fetal circulation versus neonatal circulation • Immature hepatic and renal metabolic pathways • Poor thermoregulatory control	• Increased likelihood of hypoxemia • Inefficient hepatic drug metabolism • Hypothermia

Perioperative Considerations

In 58% of cases, cesarean sections are performed on an emergency basis [7]. Conditions such as dehydration, hypovolemia, hypotension, exhaustion, hypothermia, toxemia, hypoxia, hemorrhage, and shock may be present if dystocia has been prolonged. Emergency cesarean sections are associated with a significantly higher risk of maternal mortality (12.7%) and reduced puppy survival compared to elective cesarean sections (3.6%)[7]. Puppies delivered via elective cesarean sections benefit from reduces exposure to birth stress, timely intervention, and immediate neonatal care, which enhance their survival rates. Small brachycephalic breeds (due to fetopelvic disproportion), large breeds (due to uterine inertia), and primigravid dogs are more susceptible to dystocia [8]. In this cases, there is an increasing likelihood of requiring emergency cesarean sections and a higher mortality risk due to maternal distress, delayed interventions and inadequate preparation.

Elective cesarean delivery may be requested for various reasons, including previous dystocia, breeds with a high risk of dystocia (e.g., bulldogs), the value of the dam and litter, and convenience. Elective cesarean sections are planned in advance, performed at an optimal time for both the dam and the puppies, close to full term. Canine gestation is typically consistent, averaging 63 ± 1 days from the luteinizing hormone surge to birth. However, the gestation period can vary from 57 to 72 days, making mating dates an unreliable predictor of the parturition date. Accurate prediction can be achieved by measuring serum progesterone levels, as it drops to less than 2 ng/ml within 24 hours before parturition, or by trans-abdominal ultrasonography to measure the gestational sac in early pregnancy or the parietal diameter in late pregnancy. A decrease in core body temperature below 37.8°C, due to decreasing progesterone levels, indicates birth is likely within 24 hours. Ultrasonography monitoring of the fetus in late pregnancy with veterinary-specific fetal monitors can detect early fetal stress. The advantage of elective cesarean sections includes the ability for the veterinary team to be prepared with the necessary equipment, medications and protocols in place, which all helps in minimizing the risk to ensure optimal operative and staffing conditions, potentially reducing neonatal mortality.

To minimize respiratory depression in pups due to exposure to inhalant anesthetics, it is recommended that the time from induction to delivery be kept as short as possible. Prior to anesthetic induction, all necessary equipment and personnel for anesthetic induction and maintenance, perioperative management, surgery, and neonatal

resuscitation should be fully prepared and on hand. The dam should be handled calmly and quietly to reduce excitement and avoid catecholamine release, which can decrease blood flow to the uterus and fetus. An intravenous catheter should be placed to facilitate perioperative intravenous fluid therapy and drug administration. Any abnormalities in electrolytes, acid-base balance, calcium, or glucose levels should be addressed before surgery. Preoperative surgical clipping of the abdomen can reduce the time from induction to delivery. To further minimize this time, the surgeon and surgical instruments should be prepared before anesthesia induction. To minimize fetal exposure to anesthetics, it's recommended to wait 15 to 20 minutes between anesthesia induction and delivery[4]. This waiting interval allows time for the drug concentration in the mother's blood to lower. As a result, the amount of the drug reaching the fetus is reduced.

Sufficient support personnel are essential for managing anesthesia induction and maintenance, anesthetic monitoring, surgical preparation, and neonatal resuscitation. A designated area equipped with all necessary tools for neonatal resuscitation should be set up beforehand, with clearly defined roles assigned to team members for handling the neonates. Ideally, there should be one dedicated individual per expected puppy to ensure effective neonatal resuscitation during delivery.

Hypotension due to aortocaval compression in the supine position is well-documented in pregnant women. Early veterinary literature suggested that full-term pregnant dogs might experience similar issues. However, research on both large and small full-term pregnant dogs indicates that dorsal (supine) positioning does not lead to significant aortocaval compression or maternal hypotension. This is likely because dogs have a bicornuate uterus and multiple fetuses, reducing direct pressure on the caudal vena cava, and benefit from greater collateral circulation compared to humans. However, most of clinic's protocol suggested placing the dam turned ¾. The patient's head should not be inclined downward, as this can increase abdominal pressure on the diaphragm, severely compromise ventilation, exacerbate maternal and fetal hypoxemia, and increase pressure on the lower esophageal sphincter, raising the risk of regurgitation. Additionally, warming the operating table can help prevent maternal hypothermia.

The surgical technique for cesarean section via hysterotomy is well established. A notable variation that significantly reduces anesthetic time, especially for a highly compromised dam, is the en bloc ovariohysterectomy [9]. In this procedure, the ovarian and uterine stumps are clamped, and the uterus, still containing the fetuses, is removed within 60 seconds of clamping. The neonates are then delivered from the uterus outside

the abdominal cavity and resuscitated by assistants. This technique has shown neonatal survival rates comparable to those reported for other methods used in managing dystocia, whether medically or surgically.

Indications for performing an ovariohysterectomy after the delivery of neonates include the presence of a grossly infected or gangrenous uterus, emphysematous fetuses, severe toxemia, or extremely prolonged dystocia [10]. Hypotension is a significant concern when performing a concurrent ovariohysterectomy and should be preemptively managed with intravenous fluid boluses before the uterus is removed. Maternal morbidity, as measured by the length of hospital stay and postoperative complications, is higher in dams undergoing a cesarean section with concurrent ovariohysterectomy compared to those having a cesarean hysterotomy alone [11]. However, performing an ovariohysterectomy during a cesarean section does not negatively impact lactation.

An uncomplicated cesarean section is classified as a clean-contaminated procedure, and routine perioperative prophylactic antibiotics are not typically indicated. However, perioperative intravenous antibiotic therapy is recommended if fetal death has occurred, uterine infection is suspected, there has been a break in aseptic technique, or there is gross evidence of infection (e.g., decomposed fetus, gangrene). Antibiotic selection should target the expected microbial population, including *Escherichia coli* and *Staphylococcus* species. First- or second-generation cephalosporins, such as cefazolin or cefoxitin, are appropriate choices for perioperative intravenous use. The routine use of postoperative antibiotics after an uncomplicated cesarean section is not warranted, nonetheless, a recent study confirmed a case of transmission of *Staphylococcus pseudointermedius* through a dam's milk causing a neonatal sepsis in a puppy after an elective cesarean section [12]. The protocol for administering antibiotics during cesarean sections in dogs varies by country due to differences in veterinary practices, regulations, and antibiotic resistance patterns as well.

Neonatal Resuscitation:

Neonates delivered by cesarean section require vigorous resuscitative efforts to help them adapt to breathing and stabilize their cardiovascular function because they exhibit a higher mortality rate at birth and within the first 24 hours of life compared to naturally delivered puppies. Additionally, puppies from brachycephalic dams have an

elevated mortality rate compared to those from non-brachycephalic breeds, warranting extra attention and effort in resuscitating this specific subpopulation [13].

To ensure the survival of neonates delivered by cesarean section, it is essential to remove placental membranes from the neonate's body and head. Clearing the airways with gentle suction of the mouth and nose suing a bulb syringe or aspirator. Swinging the neonate to remove secretions, although a common practice, offers no advantage over careful suctioning and can potentially be harmful if the head and neck are not properly supported. Stimulation of the chest wall should be vigorous to remove placental fluids and promote spontaneous breathing. Vocalization indicates adequate lung expansion. Once spontaneous respiration begins, any residual inhalant anesthetic in the neonate will be quickly eliminated. Neonates often experience hypoxemia after birth, as evidenced by fetal bradycardia. Supplemental oxygen should be administered via a face mask or by placing the puppies in an oxygen induction chamber once they are breathing spontaneously. In severe cases of respiratory depression with hypoxemia, labored breathing or cyanosis consider endotracheal intubation using a small endotracheal tube or a tomcat or intravenous catheter to facilitate more efficient oxygen delivery through manually assisted ventilation.

Neonates possess a high surface area to body-weight ratio and limited thermoregulatory capabilities, rendering them highly vulnerable to hypothermia. Dry the neonate thoroughly and place them under a radiant warmer. Use warmed blankets to maintain body temperature. The umbilical cord should be clamped and ligated approximately 2 cm from the body wall, followed by removal of the placenta beyond this point.

Reversible agents that could potentially cause respiratory or CNS depression in neonates should be promptly antagonized. For neonates exposed to opioids through maternal administration, naloxone can effectively reverse their depressant effects (see later)[14]. Close monitoring is crucial due to naloxone's shorter duration of action compared to many opioids, which may necessitate a second dose if narcosis reoccurs.

Flumazenil, a specific benzodiazepine antagonist, can be administered intravenously or via the umbilicus to counteract the effects of benzodiazepines [15].

Doxapram, a general CNS stimulant, stimulates respiration by directly activating medullary respiration centers and possibly through reflex activation of carotid and aortic chemoreceptors. The use of doxapram in neonate puppies after cesarean section can be an effective intervention to stimulate breathing in those with apnea or significant

respiratory depression. Nonetheless a recent study did not find sufficient evidence to support a benefit or disadvantage of intralingua doxapram compared to saline when routinely administered to non-apneic puppies delivered by elective cesarean [16]. Early veterinary literature advocated for routine use of doxapram in neonates delivered by cesarean section. However, this recommendation was based on a retrospective study with a limited sample size, lacked a control group, and did not track puppy survival beyond discharge. Current pharmacodynamics insights suggest that doxapram's short duration of action may limit its effectiveness in hypoxic neonates. Therefore, instead of routine and indiscriminate use, doxapram should be reserved for neonates that are apneic but not hypoxic during neonatal resuscitation efforts. Initial interventions should prioritize oxygen supplementation, manual stimulation of respiration, provision of radiant heat, and reversal of opioids or benzodiazepines.

Acupuncture at the GV26 site (i.e., nasal philtrum) has anecdotally been reported to stimulate respiration in neonates. Only few studies have been conducted to evaluate this method against standard resuscitation techniques, so it is not considered a fail-safe method and its true efficacy remain to be determined at this time [17].

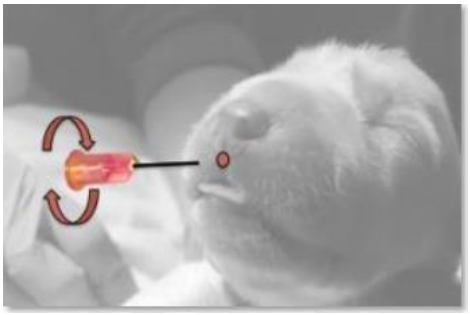

Figure 3. Acupuncture GV26 in puppy

For assessing the health of newborn puppies immediately after birth, the Apgar score is a critical tool, guiding necessary medical interventions. This scoring system evaluates five criteria: heart rate, respiratory effort, muscle tone, reflex irritability, and color, each rated from 0 to 2. A total score of 7-10 indicates good health, 4-6 suggests the need for some resuscitative efforts, and 0-3 signifies critical condition requiring immediate, aggressive intervention. The APGAR score is used in several of studies to assess the puppy vitality for different usage of drugs.

Preoperative Assessment

The preoperative assessment, inclusive of signalment, history, physical examination, and laboratory findings, guides the selection of the most suitable anesthetic. A comprehensive clinical examination, encompassing the general medical history and pertinent reproductive system details, is imperative, with particular attention to labor progression. Owners should be queried for historical data regarding anesthesia, surgeries, illnesses, and prior medications. The physical examination must be thorough, tailored to the bitch's condition, including palpation of the abdomen to evaluate uterine size and tone, along with digital vaginal and rectal examinations. Vaginoscopy may be warranted in cases of suspected obstructive pathology. Employing abdominal radiography and/or ultrasonography is vital for assessing fetal presence, number, size, and viability, with ultrasonography offering superior sensitivity over radiography in discerning live versus freshly deceased fetuses, and enabling measurement of fetal movement and heart rates. Laboratory investigations, including packed cell volume, total protein, blood urea nitrogen (BUN), calcium, glucose, and electrolyte levels, are advised before administering cesarean section anesthesia to detect acid-base disturbances and guide fluid therapy[2]. Nonetheless, in emergency cesarean sections, therapy may need to commence before obtaining test results.

Pre-oxygenation

Dogs in late pregnancy face heightened susceptibility to hypoxemia due to a decreased functional reserve capacity and increased metabolic rate [2]. Parturient animals experience a 20% rise in oxygen consumption, prompting a 40% increase in tidal volume and a 10% elevation in respiratory frequency, culminating in a 50% boost in alveolar ventilation. Simultaneously, the gravid uterus displaces the diaphragm cranially, diminishing total lung volume and functional residual capacity by 20% [18]. Consequently, oxygen supplementation becomes imperative, as failure to preoxygenate can swiftly precipitate hypoxemia, exacerbated by frequent apnea induced by anesthetic agent induction. Maternal hypoxemia poses the risk of fetal hypoxia and acidosis. Administering 100% oxygen via face mask for 3-5 minutes (at a flow rate of 4 to 6 L/min) before and during general anesthesia induction is strongly recommended, with premedication aiding in mitigating potential stress associated with face-mask oxygenation.

Premedication

Premedication with anti-emetic drugs is recommended to mitigate the risk of regurgitation, vomiting, and aspiration of gastric contents during cesarean section. Intra-abdominal procedures, increased gastric acidity, and elevated abdominal pressure from the gravid uterus collectively heighten the likelihood of esophageal reflux, contributing to maternal mortality. According to Lumb & Jones, the use of Atropine and Glycopyrrolate (anticholinergics) is advocated to decrease salivation and gastric motility, thereby reducing regurgitation and aspiration risk. Notably, Glycopyrrolate exhibits limited placental transfer compared to atropine, minimizing its impact on the fetus [18]. Human studies comparing glycopyrrolate and ondansetron for nausea and vomiting during cesarean section revealed no significant difference in efficacy, although the glycopyrrolate group exhibited significantly fewer episodes of bradycardia albeit a higher incidence of dry mouth [19]. Similarly, metoclopramide administration in humans undergoing cesarean section demonstrated a significant reduction in intra- and postoperative nausea and vomiting incidence, with an additional benefit of stimulating lactation in bitches [20, 21]. However, controlled studies assessing the efficacy of these anti-emetic drugs in veterinary literature remain scarce.

Premedication with sedative drugs and analgesics is beneficial for reducing the required dose of induction and inhalation anesthetics during cesarean sections, easing the stress on the bitch, particularly in cases of ongoing parturition, prolonged second-stage labor, postpartum status, or uterine inertia. Additionally, premedication facilitates intravenous catheter placement, facilitating fluid therapy and drug administration. However, caution is warranted with sedative and analgesic combinations due to the potential for significant fetal depression. Both opioids and tranquilizers can readily cross the placental barrier, leading to neonatal respiratory and neurobehavioral depression [18]. While opioids offer sedation and analgesia with minimal cardiovascular effects, they can induce dose-dependent respiratory depression necessitating assisted ventilation and may lead to bradycardia. To counteract neonatal respiratory depression from opioids like morphine or methadone, naloxone administration is recommended [22]. Benzodiazepines such as diazepam provide skeletal muscle relaxation and mild sedation but can exacerbate opioid-associated respiratory depression. Neonatal depression may occur following diazepam or midazolam exposure, characterized by lethargy, hypotonia, apnea, and hypothermia immediately after birth [18]. Use of benzodiazepines should be cautious,

with dosage optimization to mitigate adverse effects, while flumazenil serves as a specific antagonist for benzodiazepine effects. Alpha2-agonists like xylazine are not recommended due to their association with increased puppy mortality, heightened risk of death in dogs, and significant maternal and neonatal cardiovascular depression [13, 23–26]. Additionally, xylazine exhibits an oxytocin-like effect on the uterus [27]. While there is no recent literature on medetomidine or dexmedetomidine, if utilized, atipamezole administration is advised in neonates to reverse their effects [28].

Intravenous Fluid Therapy

Intravenous fluid therapy is strongly advocated for dogs undergoing cesarean section to ensure adequate uterine blood flow crucial for maintaining appropriate neonatal blood pressure [29]. Despite this, a survey revealed that in 53% of the case, fluid therapy was administered only during cesarean sections [30]. Initiation of fluid therapy preoperatively is essential to correct fluid deficits, electrolyte imbalances, or acid-base disturbances prior to surgery [30]. Crystalloid solutions, particularly lactated Ringer's solution administered at a rate of 10 to 20mL/kg/hour, are preferred for their ability to increase maternal blood pressure and mitigate hypotensive effects induced by anesthetic drugs [15, 31]. Colloid solutions like HES or dextran have shown efficacy in reducing the incidence of hypotension in human medicine, but data in veterinary medicine are scarce [32]. In cases of severe blood loss, blood transfusion with whole blood or packed red blood cells may be necessary, especially in instances of peripartum hemorrhage (PPH) [33]. Although there is no standardized approach to managing PPH in dogs, blood typing and availability of fresh blood are ideal for anticipated severe hemorrhage. Human studies comparing prophylactic ephedrine infusion versus fluid preload for combating hypotension during spinal anesthesia for Cesarean sections revealed conflicting results, with ephedrine use associated with fetal acidemia and lower umbilical artery pH [34, 35].

Local and Regional anesthetic techniques

Local infiltration of field block presents several drawbacks compared to regional techniques. This method necessitates larger amounts of anesthetic agents, leading to potential fetal depression due to absorption. Moreover, muscle relaxation and analgesia achieved through infiltration are typically less profound and uniform compared to

regional anesthesia. Often, field block is supplemented with heavy sedation or tranquilizers in high doses to calm and stabilize the dam, exacerbating maternal and fetal depression. Consequently, field block is frequently replaced by either general or epidural anesthesia for cesarean sections.

Regional anesthesia, including epidural or subarachnoid techniques, can effectively serve as the primary method for performing cesarean sections in dogs. The procedure for epidural injection is thoroughly documented, typically administered at the lumbosacral or sacro-coccygeal space in larger dog breeds [36, 37]. However, it is advisable to heavily sedate the dog, typically using a combination of acepromazine and morphine [36]. An important consideration during epidural blockade is the prevention of associated hypotension resulting from the injection of local anesthetic agents. Sympathetic blockade during epidural anesthesia may induce maternal hypotension, compromising uterine perfusion, emphasizing the need for prompt fluid therapy as mentioned earlier. Additionally, vasopressors such as ephedrine can be utilized [18] (refer to previous paragraph). Notably, a retrospective study found no significant difference in the incidence of hypotension between dogs anesthetized without epidural and those with low-dose epidural bupivacaine with fentanyl or buprenorphine [38].

Esters of p-aminobenzoic acid, such as procaine or tetracaine, are metabolized by maternal and fetal pseudocholinesterase, resulting in minimal accumulation in the fetus [18]. In contrast, amide derivatives (lidocaine, mepivacaine, bupivacaine, etidocaine, and ropivacaine) are metabolized by hepatic microsomal enzymes, potentially leading to significant fetal concentrations after absorption from the injection site, with neonatal blood levels exceeding those of lidocaine or mepivacaine possibly causing neonatal depression at delivery [18]. However, concentrations causing fetal depression rarely occur after epidural administration. The duration of block appears to be influenced by the protein binding capacity of the drugs, with lidocaine and mepivacaine exhibiting durations of action of 1.5 to 4 hours, whereas bupivacaine and ropivacaine have prolonged durations of action of 3 to 6 hours [36]. A reduced volume of 2% lidocaine at 1mL/6kg is typically effective for cesarean sections. With epidural anesthesia, endotracheal intubation is not performed in the bitch; therefore, supplemental oxygen can only be administered by face mask or nasal insufflation, increasing the risk of aspiration of regurgitated material. Prolonged epidural anesthesia can occasionally result in postoperative hind limb paralysis and urinary retention. Administering inhalation anesthesia to the dam after delivery of the puppies facilitates closure of the uterus and

body wall. Regional epidural anesthesia is a preferred technique for cesarean sections due to minimal fetal exposure to anesthetics, resulting in more vigorous puppies at birth [39]. Studies have shown that epidural anesthesia usage following induction and halothane maintenance yields better Apgar scores for puppies [30]. Additionally, epidural anesthesia reduces the requirement for isoflurane in dams undergoing cesarean section and does not adversely affect neonatal umbilical blood gas results, with newborns from epidural anesthesia recovering more quickly postnatally [30]. Combining inhalation and epidural anesthesia, compared to inhalation alone, influences neonatal outcomes during cesarean section in dogs, with higher isoflurane concentrations and longer exposure times having negative effects on initial newborn vitality and umbilical cord blood gas parameters [40]. Incorporating an epidural component allows for lower concentrations of inhalation agents and contributes to better clinical conditions for newborns during cesarean sections. Furthermore, a retrospective study on lumbosacral epidural analgesia during cesarean section surgery in 182 dogs demonstrated that lumbosacral epidural anesthesia was associated with lower rates of opioid administration and did not exacerbate the incidence of hypotension [38].

General Anesthesia Technique

Induction

The induction of anesthesia marks the transition from wakefulness to an anesthetized state. It is crucial to keep the time interval between induction and pup delivery minimal. Shortening this interval is highly beneficial, as it significantly enhances neonatal survival rates. To achieve this, induction can be performed in the operating room post-abdominal clipping to eliminate the need for patient repositioning and transportation post-induction. The primary goal of induction agents is to swiftly induce unconsciousness, facilitating prompt endotracheal intubation for airway protection and ventilatory assistance.

Inhalation induction of anesthesia can be conducted using a mask or chamber. Lumb & Jones [18] suggest that inhalational anesthetics are suitable for inducing anesthesia in tranquil or subdued mothers. However, these agents readily penetrate the placental barrier, leading to rapid equilibration between the fetus and the mother. The extent of neonatal depression is directly proportional to the depth of anesthesia induced in the mother. Isoflurane, sevoflurane, and desflurane are favored according to Lumb &

Jones [18] due to their swifter induction and recovery times for both the mother and neonates. Nitrous oxide can complement these agents, reducing the required dosage of volatile agents. Nonetheless, inhalation induction carries drawbacks such as maternal stress and hypoxemia, potentially triggering catecholamine release, maternal hypoxia, fetal hypoxia, and acidosis. Furthermore, as mentioned earlier, the induction period should be brief, but inhalational anesthesia generally takes longer than injectable induction. Additionally, there is a heightened risk of regurgitation and aspiration since the airway remains unprotected. In a recent study in human medicine investigating the impact of isoflurane concentration on awareness, postoperative depression, anxiety, and stress in patients undergoing cesarean section [41], it was suggested that reducing inhaled anesthetic doses and employing alternative IV anesthetics to maintain anesthesia depth is advisable when feasible. Due to these concerns, the literature recommends [15] the use of injectable anesthetics for induction instead of inhalational induction in patients undergoing cesarean section.

Propofol, a rapid, ultra-short acting nonbarbiturate injectable induction agent, has been linked to favorable neonatal outcomes, akin to those observed with epidural anesthesia in the dam [22]. While propofol readily crosses the placenta and reaches the fetus swiftly, there exists a placental barrier effect, resulting in higher maternal blood concentrations compared to fetal concentrations post-injection. Metabolism of propofol primarily occurs in the liver, with additional extrahepatic metabolism, leading to rapid clearance from the neonatal circulation [18]. In canine studies, propofol followed by isoflurane anesthesia yielded newborn survival rates comparable to those achieved with epidural anesthesia and superior to those observed with general anesthesia induced by thiopental [42]. Several investigations in human medicine have compared propofol use in cesarean section anesthesia with thiopental, with results indicating no significant differences in newborn outcomes post-cesarean section [43, 44]. A comparison of propofol, etomidate, thiopental, and epidural anesthesia in dogs revealed no differences in systemic effects, while epidural anesthesia exhibited superior results for neonates [39] (refer to the chapter on epidural anesthesia). In dogs and cats, the recommended induction dose of propofol ranges from 4 to 8 mg/kg IV, with supplemental doses ranging from 0.5 to 2.0 mg/kg IV [18]. Notably, propofol administration can induce hypotension, particularly in dogs with preexisting hypovolemia [15]. Management of hypotension may entail intravenous fluid boluses (refer to fluid therapy management). Transient dose- and

rate-dependent apnea, as well as respiratory depression, are common adverse effects associated with propofol use, necessitating assisted ventilation during the immediate induction period. Propofol lacks analgesic properties; therefore, adjunctive analgesics should be administered for effective surgical pain management. In human medicine, dexmedetomidine is utilized as an analgesic during cesarean section due to its rapid clearance from maternal circulation and minimal transfer to fetal circulation [45]. Medetomidine can also serve as a premedication, allowing for a reduction in the required propofol induction dose by more than half [46]. Given its pharmacokinetic profile, propofol has been and continues to be considered the preferred induction agent for cesarean section anesthesia. Presently, research endeavors aim to compare propofol usage with alfaxolone.

Thiopental, an ultra-short acting barbiturate characterized by high lipid solubility, readily traverses the placental barrier upon intravenous administration [22]. Its cardiovascular and respiratory depressant effects manifest as increased heart rate, reduced arterial pressure, and alterations in peripheral vascular resistance in both the dam and fetuses [18]. Minimizing fetal depression entails employing the lowest feasible induction dose [22]. Comparative studies investigating propofol and thiopental induction for bitches undergoing cesarean section have demonstrated no significant differences between the two agents. However, the use of thiopental is linked to decreased puppy vigor at birth, albeit not to decreased puppy survivability [22]. Consequently, propofol remains the preferred injectable agent of choice [15].

Etomidate, a short-acting non-barbiturate hypnotic, stands out for its minimal cardiovascular effects in dogs [18]. As such, it is the preferred agent for inducing anesthesia in compromised dams or those with pre-existing cardiac conditions. Research conducted on ewes indicates that while etomidate exhibits rapid placental transfer, a certain placental barrier effect limits its transmission. Furthermore, there is no evidence of drug accumulation in the fetus due to the rapid elimination of etomidate [47]. In studies involving pregnant women, concentrations of etomidate in maternal plasma, umbilical venous plasma, and colostrum post-anesthesia induction declined more rapidly compared to thiopental [48]. The clinical condition of newborns was deemed superior with etomidate compared to thiopental in women [49]. However, a notable side effect of etomidate is myoclonus or involuntary movements upon injection. Therefore, administration of benzodiazepines (such as midazolam) or opioids can mitigate the dosage requirements of etomidate and enhance intubation conditions [50]. However, it is

essential to note that premedication with opioids or midazolam may exacerbate neonatal depression. Additionally, etomidate frequently induces pain and irritation upon intravenous injection in non-premedicated patients [18]. To address this issue, it is recommended to dilute etomidate to a 50:50 ratio with 0.9% saline solution [15]. One significant drawback of etomidate is its considerably higher cost compared to other induction agents.

Ketamine, a dissociative drug, finds utility in dogs at low doses ranging from 3 to 5 mg/kg IV for anesthetic induction [18]. A comparative study evaluating four anesthetic protocols (epidural anesthesia, thiopental, midazolam/ketamine, and propofol) on the neurological and cardiorespiratory variables of puppies delivered by cesarean section revealed distinct outcomes. Notably, epidural anesthesia was associated with the highest respiratory rate, while the most depressed neurological reflexes were observed following midazolam/ketamine induction, followed by thiopental, propofol, and epidural anesthesia [51]. Another investigation concluded that anesthetic factors linked to increased puppy vigor included the use of isoflurane and the avoidance of ketamine and thiopental [13]. However, caution is advised in the use of ketamine, as it may heighten the risk of respiratory depression, apnea, decreased vocalization in puppies, and increased mortality at birth [18]. In summary, while ketamine induces less cardiovascular depression in dams compared to propofol or thiopental, it exerts significant depressant effects on neonates [15].

Saffan®, a blend of two progesterone-like steroids (alfaxolone, 9mg/mL; and alfadolone, 3mg/mL), is not recommended for use in dogs due to its solubilizing agent (cremaphore), which triggers severe histamine release [18]. However, Alfaxan-CD has gained acceptance in many countries as it incorporates alfaxolone solubilized in a cyclodextrin carrier, thereby preventing histamine release. Numerous studies have focused on comparing alfaxolone and propofol, particularly regarding outcomes for both the mother and puppies. A recent study investigating the effects of alfaxolone or propofol on the viability of neonates from giant breed dogs during elective cesarean sections [52] revealed that alfaxolone induction led to improved puppy viability (positively correlating with Apgar scores) compared to propofol. Similarly, another recent study utilizing a modified Apgar score found that alfaxolone resulted in significantly better puppy vitality within the first 60 minutes post-delivery compared to propofol. However, both alfaxolone and propofol yielded similar puppy survival rates [53]. A knowledge summary comparing alfaxolone versus propofol as anesthetic induction agents in enhancing neonatal survival

and vigor, drawn from multiple studies, concluded that while two studies favored alfaxolone with higher Apgar scores for neonates, both agents demonstrated positive vigor and high survival rates [54]. In conclusion, the evidence does not decisively favor one induction agent over another. Lumb and Jones assert that alfaxolone is an effective short-acting anesthetic with minimal cardiopulmonary depression and few adverse effects, rendering it acceptable for use in cesarean section surgery [18].

Fentanyl, a short-acting opioid renowned for its potent analgesic properties, has been utilized for profound sedation and analgesia in clinical settings. Following fentanyl administration, many dogs can be successfully intubated, often in combination with either diazepam or midazolam. However, a comparative study between co-inductions of fentanyl/propofol and midazolam/propofol revealed that while fentanyl reduced propofol requirement without significant alterations in cardiovascular parameters, midazolam failed to decrease propofol requirement and induced excitement in some subjects [55]. Drawbacks associated with fentanyl encompass maternal respiratory depression necessitating assisted ventilation and potential bradycardia. Maternal bradycardia can be effectively managed with atropine or glycopyrronium. Given its opioid nature, the depressant effects of fentanyl can be reversed in neonates through naloxone administration. A comparative assessment of the clinical efficacy and cardiorespiratory effects of alfaxolone versus diazepam/fentanyl for anesthesia induction in dogs demonstrated similar outcomes [56]. Specifically, anesthesia induction with alfaxolone elicited comparable cardiorespiratory effects when juxtaposed with the fentanyl-diazepam-propofol combination. When fentanyl is employed in conjunction with other induction agents such as propofol and thiopental, the doses of these agents are typically reduced. It was observed that fentanyl significantly decreased the alfaxolone induction dose and responses to noxious stimuli [57]. In situations where repeated or intra-operative re-dosing is anticipated, fentanyl is favored due to its lower likelihood of accumulation in an acidotic fetus compared to longer-acting opioids. Furthermore, fentanyl can be administered as a continuous rate infusion (CRI) post-induction in combination with inhalation anesthesia to diminish the minimum alveolar concentration (MAC) and provide additional analgesia. In the event of utilizing a CRI opioid, discontinuation of the infusion approximately 30 minutes before the conclusion of the procedure is advisable to facilitate prompt anesthetic recovery without respiratory depression [15]. Propofol and fentanyl infusions have demonstrated efficacy in maintaining stable cardiovascular function and providing satisfactory surgical conditions [58].

Benzodiazepines, including midazolam and diazepam, are occasionally combined to significantly reduce the dosage of induction agents such as propofol and alfaxolone. Research has investigated the dosage and cardiopulmonary effects of propofol administered alone versus in combination with midazolam for anesthesia induction. The findings indicated that midazolam co-induction reduced the propofol induction dose and enhanced the quality of induction without a notable improvement in cardiopulmonary variables compared to higher doses of propofol administered alone [59]. However, caution is warranted in the use of benzodiazepines due to their lipophilic nature, facilitating their easy passage across the placental barrier. Moreover, neonatal elimination of benzodiazepines is sluggish owing to immature hepatic enzyme development. In a comparative analysis of four distinct anesthetic protocols on the neurological and cardiorespiratory variables of puppies delivered by cesarean section, the midazolam/ketamine protocol resulted in the most pronounced depression of puppies [51]. Nonetheless, it is crucial to note that adverse effects of benzodiazepines can be efficiently reversed by administering flumazenil in dogs.

Maintaining Anesthesia

Utilizing inhalation anesthesia with a cuffed endotracheal tube facilitates the delivery of elevated concentrations of inspired oxygen and enables precise control of assisted ventilation. However, owing to their lipid solubility and low molecular weights, inhalation agents readily traverse the placenta, leading to rapid equilibration between the fetal and maternal compartments. These agents elicit potent cardiovascular and respiratory depression, with the degree of neonatal depression directly correlated to the depth of anesthesia induced in the mother. Consequently, deep maternal anesthesia levels can precipitate hypotension in the dam, reduce uterine blood flow, and induce fetal acidosis [18]. To mitigate the risk of neonatal respiratory depression, inhalation anesthetic concentrations should be maintained at minimal levels, as neonates eliminate these agents rapidly once spontaneous respiration commences [15].

During pregnancy in animals, the minimum alveolar concentration (MAC) of inhalation anesthetics decreases by 25% for halothane and 28% to 40% for isoflurane [15]. Delivery of inhalation anesthetics should be titrated to effect. Halothane, isoflurane, sevoflurane, and desflurane are commonly used as maintenance inhalation anesthetics.

A study in human medicine [60] compared the maternal and neonatal effects of isoflurane and halothane combined with a 50% N2O – 50% O2 mixture in healthy parturient patients undergoing cesarean section, finding no significant differences in neonatal outcomes among the three groups. Isoflurane was considered a safe supplement to the N2O – O2 mixture for cesarean section, suggesting its preferential use over halothane in cases where patients receiving beta-adrenergic therapy require cesarean section due to potential arrhythmia risks associated with halothane. Similarly, a prospective study [61] evaluated the maternal and neonatal effects of desflurane in obstetrical human patients undergoing cesarean section, finding no significant differences in maternal blood loss or intraoperative awareness among groups receiving different concentrations of desflurane or enflurane. Neonatal outcomes were similarly favorable across groups, with a higher incidence of delayed sustained respiration observed in the 6% desflurane group compared to the 3% desflurane group. According to research [15], isoflurane usage is associated with higher neonatal survival rates compared to halothane or methoxyflurane, making it the preferred choice over halothane in emergency cesarean sections. Although not specifically studied in veterinary cesarean section anesthesia, desflurane and sevoflurane exhibit cardiopulmonary depressant effects similar to those of isoflurane. Methoxyflurane is discouraged as a maintenance inhalation agent due to its association with decreased puppy survival. Nitrous oxide usage during cesarean sections should be avoided or limited to expediting inhalant induction and discontinued upon the dam's intubation, as it diminishes maternal inspired oxygen concentration and poses a risk of diffusion hypoxia in neonates.

Anesthetic Monitoring:

It is imperative to maintain precise and continuous monitoring of cardiovascular and ventilation parameters, temperature, and the depth of anesthesia throughout anesthetic procedures, particularly during cesarean sections [18].

Cardiovascular Monitoring

Various methods can be employed for monitoring anesthesia in cesarean bitch surgery. Heart rate assessment can be conducted through pulse detection, esophageal stethoscope, electrocardiography (ECG), or pulse oximetry. Arterial pulse can be directly palpated at several sites, including the lingual, digital, or pedal arteries, to ascertain the difference between systolic and diastolic pressures. However, it's important to note that

pulse quality and magnitude may not reliably indicate cardiac output, blood pressure, or tissue perfusion [62]. Arterial blood pressures may also be dependent on anatomic location and body position [63].

Esophageal stethoscopes offer a simple and cost-effective means of monitoring heart sounds [64]. However, they may not provide adequate warning of circulatory insufficiency. Electrocardiography records the electrical activity of the heart and provides heart rate data, but it does not offer information regarding cardiac contractility or blood pressure. Furthermore, erroneous results may occur due to interference, thus electrocardiography alone should not be solely relied upon for monitoring heart function.

Most pulse oximeters offer pulse rate measurements and oxygen saturation (SpO2) monitoring. Injectable and inhalation anesthetics often induce decreased cardiac output and systemic vascular resistance, leading to hypotension and potentially poor tissue perfusion. Blood pressure monitoring is crucial and can be achieved through direct or indirect techniques. Direct blood pressure monitoring via arterial catheterization is considered the gold standard, providing accurate and continuous readings of systolic, diastolic, and mean blood pressures [15].

Noninvasive blood pressure monitoring techniques, such as Doppler flow detection and oscillometric methods, offer alternatives. Doppler flow detection with a sphygmomanometer provides an estimate of systolic arterial pressure but does not yield information on diastolic or mean blood pressures. Oscillometric techniques, on the other hand, automatically measure systolic, mean, and diastolic blood pressures, along with pulse rate. Although these methods offer acceptable estimates of blood pressure, the oscillometric technique is relatively more expensive and may present reliability issues in very small animals [65].

Hypotension is a common complication during anesthesia, particularly in cesarean section surgeries, due to the cardiac depressant effects of anesthetics and other factors such as hemorrhage and increased intra-abdominal pressure. Treatment of hypotension involves decreasing anesthesia depth and administering crystalloid fluid boluses. If crystalloid therapy proves ineffective, synthetic colloids such as hetastarch can be administered. Opioids, administered via intravenous bolus or continuous rate infusion, can reduce the concentration of inhalation anesthetics and potentially improve blood pressure and tissue perfusion. Anticholinergics may be used to increase heart rate and improve cardiac output in cases of bradycardia. Inotropes such as dobutamine, dopamine,

epinephrine, and ephedrine may also be employed to enhance cardiac contractility and increase blood pressure in refractory hypotension cases [34].

Respiratory Monitoring

Arterial blood gas (ABG) analysis stands as the gold standard for assessing ventilation, arterial oxygenation, and acid-base status in anesthetized animals. This technique entails well-defined procedures for arterial sampling and interpretation.

Capnography offers a valuable means to evaluate ventilation by measuring the end-tidal carbon dioxide concentration, which closely reflects the alveolar carbon dioxide concentration, and by extension, the partial pressure of arterial carbon dioxide (PaCO2). Although capnography readings typically approximate the lowest value for PaCO2, true PaCO2 values may surpass the displayed readings. Notably, if PaCO2 exceeds 55 mm Hg, commercial capnometers may underestimate it by up to 20 mm Hg [15]. Capnography primarily serves as a trend analysis tool and does not supplant ABG analysis in assessing ventilation adequacy.

Pulse oximetry presents a noninvasive approach to monitor the arterial oxyhemoglobin saturation (SpO2) and pulse rate of the dam during anesthesia. However, the relationship between SpO2 and arterial blood gas measurements of PaO2 is not linear. Generally, animals maintain adequate oxygenation with SpO2 levels above 90%, corresponding to PaO2 levels exceeding 60 mm Hg. SpO2 measurements offer real-time indications of arterial oxyhemoglobin saturation trends during surgery but do not substitute for ABG analysis as the definitive method for assessing arterial oxygenation.

Respiration can be monitored through direct observation of thoracic wall movement and subjective assessment of breathing bag excursions. Electronic respiratory monitors can supplement monitoring efforts but do not replace the necessity for direct respiration monitoring or provide insights into ventilation effectiveness [66].

Temperature Monitoring:

Maternal hypothermia presents a significant concern during cesarean sections. Monitoring the core body temperature is imperative, typically accomplished using either an esophageal or rectal probe for accurate measurement. To support body temperature, various methods are employed: Heated operating tables are utilized to provide warmth from below the patient. Intravenous fluids and abdominal lavage fluid are warmed before administration to counteract heat loss. Radiant heat lamps are strategically positioned

around the patient to emit infrared radiation, promoting warmth. Circulating warm-air blankets envelop the patient in a cocoon of warm air, aiding in temperature regulation. By employing these methods, healthcare providers can effectively mitigate the risk of maternal hypothermia, ensuring optimal conditions for both the mother and the newborn during the procedure.

Postoperative Care of Dams:

Post-operatively, oxytocin is employed to facilitate uterine contractions, helping the uterus to return to its normal size (involution) and reduce post-partum bleeding. It is also efficient to promote milk letdown, ensuring that the neonates can nurse effectively. Effective analgesia after the cesarean section, for dams is crucial to promote early active suckling of neonates. Local infiltration of surgical wounds with lidocaine (2 mg/kg) or bupivacaine (2 mg/kg, alone or in combination with lidocaine) is recommended for regional analgesia as part of a comprehensive anesthetic regimen. The volume of local anesthetic can be adjusted by diluting it with 0.9% sodium chloride solution to achieve the desired total volume [4]. Epidural analgesia can be administered using various agents, with morphine being the most commonly used (see epidural anesthesia). Parenteral opioids after surgery, offer robust pain relief and can be administered via injection, orally, or transdermally, albeit with the potential for sedation. Nonsteroidal anti-inflammatory drugs (NSAIDs) can be used alone or in conjunction with opioids to enhance analgesic efficacy. Tramadol, an opioid-like drug, provides analgesia, particularly effective when combined with an NSAID, and has few apparent side effects.

Discussion: The evolution of Anesthetic Protocol in Cesarean bitches

In summary, as discussed in this literature review, we can compare the protocols of the 1990s, primarily guided by the work of Lumb & Jones [18], with contemporary protocols.

Firstly, pre-oxygenation of the dam was demonstrated to be essential due to a 20% increase in oxygen requirements associated with the gravid metabolism.

Regarding premedication, veterinarians often administered acepromazine, benzodiazepines (such as diazepam), or alpha-2 agonists (such as xylazine or medetomidine). Today, studies have shown that xylazine is not recommended due to its

association with increased puppy mortality, maternal and neonatal cardiovascular depression, and oxytocin-like effects on the uterus. Research on medetomidine remains limited and should be pursued. In elective cesarean protocols, WSAVA guidelines recommend acepromazine in combination with opioids during the preoperative phase, especially if the dam requires more sedation. Benzodiazepines such as diazepam or midazolam are preferred in emergency cesarean cases; midazolam is particularly favored due to its reduced placental transfer.

An antiemetic is recommended for the dam due to the pressure of the uterus on the stomach and the risk of aspiration pneumonia. Metoclopramide is preferred over acepromazine and other molecules, due to its pro-lactic effect and its support for post-surgical lactation production.

Intravenous fluids are highly recommended to maintain appropriate blood pressure in both the dam and the puppies. Historically, fluids were administered only at the time of surgery, but current best practices advocate for fluid administration in the preoperative phase as well. Lactated Ringer's solution is particularly recommended to reduce the incidence of hypotension in the dam and to mitigate the hypotensive effects of anesthetic agents.

For the induction of anesthesia, thiopental was particularly popular in the past due to its rapid action. However, recent studies have associated thiopental with decreased puppy vigor at birth. Due to its potential for accumulation in adipose tissue, thiopental also results in a prolonged recovery time. Furthermore, the narrow therapeutic window between the effective dose and the toxic dose makes thiopental a less reliable and safe agent. Similarly, ketamine can accumulate in tissues, leading to prolonged recovery times and also cause increases in heart rate and blood pressure, which may be undesirable in patients with certain cardiovascular conditions or in pregnant bitches. Ketamine has an important risk capacity to cross the blood-milk barrier as well. Recent studies have demonstrated that propofol is the preferred agent. Propofol provides rapid onset and offset of action, allowing for better control over anesthesia depth. It also has antiemetic properties, reducing the risk of postoperative nausea and vomiting. Its pharmacokinetic profile is favorable, allowing for quicker recovery and fewer side effects. Notably, propofol has a placental barrier effect, resulting in higher maternal blood concentrations compared to fetal concentrations. Many studies have aimed to compare alfaxalone and propofol, and they yield similar puppy survival rates, therefore it would depends on the protocol of one’s clinic.

For maintenance, inhalant anesthetic agents such as isoflurane and halothane have been used to maintain anesthesia. Isoflurane has gradually replaced halothane due to its improved safety profile and favorable pharmacological properties. Desflurane and sevoflurane can also be used similarly to isoflurane, with literature reporting no significant differences in terms of efficacy and safety among these agents. However, isoflurane remains the most commonly used anesthetic agent because desflurane is slightly more irritating, and sevoflurane incurs higher costs and requires specialized vaporizers.

For analgesia of the bitch and the reduction of stress, opioids remain necessary despite their ability to easily cross the placental barrier. They can affect the puppies, potentially causing respiratory depression and decreased vigor at birth, as well as delaying the onset of lactation. In premedication, an initial dose of morphine is typically administered along with midazolam. Once the puppies are delivered, a second dose of morphine is given to the bitch to complete the surgery, and naloxone (an opioid full antagonist) is recommended for the puppies. A dose of buprenorphine may also be given postoperatively to provide comfort to the bitch due to its analgesic and mildly sedative properties. Additionally, this molecule has the advantage of relatively minimal transfer across the blood-milk barrier.

Conclusion

The evolution of anesthetic protocols for cesarean sections in bitches is characterized by a continuous refinement driven by emerging research and clinical experience. The current focus on optimizing both maternal and neonatal outcomes reflects a broader trend in veterinary medicine towards evidence-based practices. Future research should continue to explore the effects of various anesthetic and analgesic agents, particularly in the context of their long-term impacts on neonates. Additionally, the development of new agents and techniques that offer improved safety and efficacy will further enhance clinical outcomes.

In conclusion, the advancements in anesthetic protocols for cesarean sections in bitches demonstrate significant progress in veterinary anesthesiology. These improvements not only enhance the safety and well-being of the dam and her offspring but also reflect a commitment to applying scientific research to clinical practice. The

ongoing evolution of these protocols underscores the dynamic nature of veterinary medicine and the continual pursuit of excellence in patient care.

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Thesis progress report for veterinary students

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Thesis title: Anesthetic protocols for canine cesarean section – a literature review

Consultation – 1st semester

	Timing			Topic / Remarks of the supervisor	Signature of the supervisor
	year	month	day		
1.	2022	09	12	Choice of Thesis Topic	
2.	2023	03	11	Bibliography/ Literature review	
3.	2023	07	31	Thesis progression	
4.	2023	08	7	Thesis progression	
5.	2023	09	15	Thesis progression	

Grade achieved at the end of the first semester: 5

Consultation – 2nd semester

	Timing			Topic / Remarks of the supervisor	Signature of the supervisor
	year	month	day		
1.	2024	01	15	Thesis progression	
2.	2024	02	13	Thesis progression	
3.	2024	03	20	Thesis progression	
4.	2024	04	18	Thesis progression	
5.	2024	05	30	Thesis progression	

Grade achieved at the end of the second semester: 5

The thesis meets the requirements of the Study and Examination Rules of the University and the Guide to Thesis Writing.

I accept the thesis and found suitable to defence.

.....
signature of the supervisor

Signature of the student: Caroline Cereuil

Signature of the secretary of the department: .....

Date of handing the thesis in: 2024 November 2nd