Foal Physiology and Special Considerations During Anesthesia

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Many veterinarians and veterinary technicians are intimidated by anesthesia of foals. General anesthetic principles for adult horses apply to foals; however, because of their age and size, foals are at risk for certain complications during anesthesia, and there are a few special considerations for determining adjustments in their anesthetic protocol. Neonatal foals (i.e., younger than 1 month) have rapidly changing cardiovascular and pulmonary physiologies as they develop adult systems, and, therefore, they have an increased risk of anesthetic-related death and/or complications. During the first week of life, a foal’s risk of anesthesia-related death is seven times higher than that of an adult horse. At 1 to 4 months of age, foals still have a higher risk for anesthetic complications and/or death, but their risk level is closer to that of adult horses.

The Transition to Adult Physiology

In utero, foals have cardiac shunts (foramen ovale, ductus arteriosus) that permit low-pressure circulation of blood. The foramen ovale permits most blood to be shunted from the right atrium into the left atrium, thereby bypassing the lungs. In addition, the relatively low-oxygen environment in utero leads to constriction of pulmonary vessels and dilation of the ductus arteriosus. Because the foal’s pulmonary arterial resistance is higher than its systemic arterial resistance, most pulmonary arterial blood is shunted through the ductus arteriosus into the aorta, with the remaining blood perfusing the lungs. During birth, neonatal foals begin the transition to a right-sided, adult cardiovascular and pulmonary physiology. The initial breaths and lung expansion after parturition (delivery) decrease pulmonary vascular resistance, increasing pulmonary blood flow. The foramen ovale and the ductus arteriosus close because of an increase in $P_{aO_2}$ (partial pressure of oxygen, arterial) and a decrease in prostaglandins. A thin layer of tissue initially closes these shunts, which permanently close over a few weeks if the foal is normal. However, if a pathologic state, such as prematurity or infection, leads to hypoxemia, acidemia (e.g., pH <7.4), or hypercapnia ($P_{aco_2}$ [partial pressure of CO$_2$, arterial]: >45 mm Hg), these shunts may reopen, and pulmonary hypertension may occur.

Neonatal foals younger than 1 week have a high resting heart rate (e.g., 60 to 120 beats/min [bpm]), high respira-
tory rate (e.g., 40 breaths/min), and low mean arterial blood pressure (MAP; e.g., 40 to 50 mm Hg) compared with adult horses. Foals also have a very compliant chest wall and have a higher oxygen requirement (e.g., 6 to 8 mL/kg/min) due to a higher metabolic demand than adult horses. Compared with adult horses, neonatal foals at birth have a lower PaO2 level (e.g., 40 mm Hg), which increases to 70 to 80 mm Hg within a few hours after delivery.2 This value can also be affected by the foal’s position: a higher level is associated with sternal recumbency; a lower level (e.g., 70 mm Hg) with lateral recumbency. Therefore, it is important to note a neonatal foal’s body position when analyzing its arterial blood gas value to decide whether medical intervention (e.g., nasal insufflation of oxygen) is necessary. In the first few weeks of life, as foals develop adult cardiovascular and pulmonary systems, their resting heart rate decreases, their respiratory rate decreases, and their MAP increases, eventually reaching adult levels (e.g., heart rate: 30 to 40 bpm; respiratory rate: 10 to 16 breaths/min; MAP: 70 to 80 mm Hg).2

Size
A typical foal (e.g., Thoroughbred) weighs 40 to 60 kg (88 to 132 lb) at birth, approximately 10% of an average adult horse. Therefore, smaller equipment (e.g., anesthetic machine, ventilator, endotracheal tubes, IV and arterial catheters) is required for foals. BOX 1 lists specific items required to anesthetize a foal.

A foal’s size also determines which anesthetic machine to use. In my experience, the small “foal” machine (which is essentially a small animal machine with a ventilator; FIGURE 2) should be used if a foal is ≤140 kg (≤308 lb) or when using a 16-mm or smaller endotracheal tube. However, it can be difficult to determine which anesthetic machine to use if foals are older and larger (e.g., 200 kg [440 lb]). When using a large anesthetic machine with these patients, it is important to reduce the amount of dead space between the patient and machine. This can be accomplished by ensuring that the endotracheal tube does not extend beyond the foal’s muzzle and, if possible, by choosing the smallest Y-tubing that will fit on the machine.

Physiologic Considerations During General Anesthesia
It is important to remember that all foals should undergo a full physical examination before general anesthesia. The cardiovascular and pulmonary systems of young foals (e.g., younger than 1 month) are in a transitional state. During the first weeks of a foal’s life, it is not uncommon to auscultate a soft, continuous flow murmur often due to a patent ductus arteriosus (PDA; FIGURE 1), which should close over time. However, occasionally, a coarse cardiac murmur may be present due to an underlying congenital cardiac defect.

During anesthesia, it is very important to maintain adequate oxygenation in neonatal foals because hypoxia (oxygen saturation: <70%), hypercapnia, and acidosis may be common in these patients. Compared with adult horses, resting foals younger than 1 week have a higher average heart rate and a lower MAP.3 Because cardiac output is determined by heart rate and stroke volume, an adequate heart rate must be maintained to maintain cardiac output when a patient is under general anesthesia. Also, during anesthesia, the MAP of neonatal foals is lower than that of adult horses. For example, the goals for a neonatal foal under general anesthesia are to maintain a heart rate >60 bpm and an MAP >50 mm Hg. As foals age, they develop an adult cardiovascular system and their resting heart rate decreases, requiring a higher MAP (e.g., >60 to 80 mm Hg). IV fluids should always be administered to offset anesthetic-related hypotension; however, to maintain adequate blood pressure, medications with mixed inotropic and chronotropic properties, such as ephedrine (0.03 to 0.06 mg/kg IV), or a positive inotrope, such as dobutamine (1 to 5 µg/kg/min by IV infusion), can be used.

A foal’s respiratory system is also not fully developed. Because of their compliant chest wall, foals do not ventilate efficiently under general anesthesia, resulting in rapid
changes in anesthetic depth and, possibly, in hypoxemia. Liver function in horses is not fully developed until approximately 2 months of age. Therefore, it is important to minimize the amount of drugs administered to foals during their first couple of months. Additionally, foals under anesthesia tend to become hypoglycemic quickly because of their high metabolic rate and low storage of energy. To reduce stress and maintain the glucose level of foals before anesthesia, it is important to allow them to nurse until induction. Because of the likelihood of hypoglycemia during general anesthesia, it is important to measure the glucose level throughout the procedure and provide a 2.5% to 5% dextrose solution, depending on the duration of surgery. I provide a 2.5% dextrose solution in saline automatically and change to a 5% solution if the glucose level drops below 100 mg/dL.

Neonatal foals cannot thermoregulate well and, therefore, are especially prone to heat loss under general anesthesia because of a lack of involuntary muscle activity (e.g., shivering), a high surface area-to-body weight ratio, and decreased nonshivering thermogenesis caused by the anesthetic drug. The increased metabolic demands of attempting to thermoregulate also contribute to the development of hypoglycemia. Therefore, foals under general anesthesia must be regularly monitored for hypothermia and hypoglycemia. I think it is important to administer warm fluids throughout surgery and use external warming devices, such as a commercially available forced-air heating blanket or warmed blankets, throughout surgery and recovery. BOX 2 summarizes the normal parameters for anesthetic maintenance.

**Induction and Analgesia**

Compared with older, larger foals, neonatal foals are easier to restrain and usually do not require chemical restraint during induction. If a foal does require additional restraint before induction, diazepam (0.05 to 0.10 mg/kg IV) may provide tranquilization and muscle relaxation (FIGURE 3). Avoid administering α₂-agonists (xylazine, detomidine) to neonatal foals because these drugs cause severe cardiovascular depression.

After induction using one of the listed protocols (BOX 3), maintenance can be achieved using isoflurane or sevoflurane (FIGURE 4). The foal’s vital parameters are monitored, and an arterial catheter line should be placed for periodic blood gas sampling (FIGURE 5).

Foals respond to intraoperative pain quickly and dramatically, even when they appear to be appropriately anesthetized. Therefore, it is important to add NSAIDs to your drug protocol. Also, butorphanol, an opiate partial agonist,
may be added to the induction protocol at a dose of 0.05 to 0.1 mg/kg IV. Regional analgesics, which can be used to decrease painful stimuli, can be a helpful addition to your anesthetic protocol.

**Fluid Therapy**

Because overhydration is possible in neonates, it is advisable to administer fluids via an infusion pump for safety (FIGURE 6). Warmed crystalloid fluids can be given at a rate of 5 to 10 mL/kg/hr. When hypotension occurs under general anesthesia, a fluid bolus of 5 to 15 mL/kg can be administered before inotropic drugs are used.

Additionally, colloids such as hetastarch may be administered at 5 to 10 mL/kg (not to exceed 20 mL/kg/day) to treat hypotension in foals. Hyperimmune plasma may also be administered if failure of passive transfer (BOX 4) occurs or to treat hypoproteinemia.

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**BOX 3**

**Induction of Anesthesia: The Author’s Protocol**

**Neonatal foal (younger than 2 wk)**
- Isoflurane or sevoflurane via nasotracheal tube
- High oxygen flow rate (3–5 L/min)
- High vaporizer setting until patient becomes recumbent (4%–6% sevoflurane; 2%–4% isoflurane), then decrease setting to maintain surgical plane of anesthesia

**Older foal (2–4 wk of age)**

**Step 1:** Xylazine (0.3–0.5 mg/kg IV): draw up a low dose and titrate to effect to decrease cardiovascular effects

**Step 2:** Ketamine (2 mg/kg IV) combined with diazepam (0.05–0.10 mg/kg IV)

**or**

Propofol (2 mg/kg IV)

**Sedation versus general anesthesia**

Sedation for short-term procedures (e.g., radiography, splint placement on a distal limb) can often be accomplished using diazepam (e.g., 15 mg IV) in an average-weight (50-kg) neonatal foal (A).
Recovery
The foal should be placed on a mattress in a well-padded recovery stall and kept warm and dry until extubation is possible (FIGURE 7). Once the foal is bright, alert, warm, and able to sit in sternal recumbency and stand, it may be placed in a stall with the dam and monitored closely for signs of discomfort or colic (FIGURE 8). If the foal requires an indwelling IV catheter, elastic adhesive tape can be wrapped loosely around the foal’s neck to secure the catheter (FIGURE 9).

Uroperitoneum
Neonates may present with a ruptured bladder and often require surgical intervention. Special anesthetic considerations for this surgery are as follows:

- Neonate (often younger than 1 week): follow the above-mentioned precautions for neonatal anesthesia
- Hyperkalemia, hyponatremia, and hypochloremia: see below

Failure of Passive Transfer
Foals cannot produce immunoglobulins in utero, and they initially obtain immunoglobulins through ingestion of colostrum. Colostrum, or “first milk,” is a thick, yellowish secretion produced by the dam’s udder a few weeks before parturition. After delivery, it is imperative for the foal to nurse from the dam, ingesting colostrum to receive initial immunity from the dam’s antibodies. Sometimes, newborn foals cannot nurse (e.g., because they are too weak or are unable to locate the udder), the mare does not produce adequate colostrum (e.g., because the mare is too ill from acute colic), or colostrum drips from the udder before parturition because of placental inflammation (placentitis), so the foals do not ingest adequate levels of maternal antibodies. These foals have failure of passive transfer of maternal antibodies and are at high risk to develop bacterial infections. However, affected foals can be given a plasma transfusion of hyperimmune plasma. A blood test (IgG test) should be performed on every foal within 12 hours after delivery to check the foal’s immune status. An IgG level >800 mg/dL denotes adequate transfer; foals with an IgG level <400 mg/dL require a plasma transfusion.
Abdominal distention: the use of a ventilator to provide intermittent positive-pressure ventilation is recommended to offset anesthetic complications that may occur with abdominal distention.

The patient should be as stable as possible when taken to surgery. However, hyperkalemia causes obvious changes on a patient’s ECG: bradycardia, increased duration of the QRS complex, a prolonged P-wave duration, spiked T waves, ventricular premature complexes, ventricular fibrillation, and cardiac arrest. The anesthetic treatment includes ventilation and administration of 0.9% saline, calcium gluconate (0.5 mL/kg), dextrose, sodium bicarbonate (NaHCO₃), and, to treat bradycardia, atropine. The key to successfully anesthetizing a foal with uroperitoneum is to stabilize the electrolyte levels before induction of anesthesia and to maintain them with the aforementioned solutions.

**Conclusion**

Compared with adult horses, foals are an anesthetic challenge because of their small size and physiologic differences. Education and experience can help veterinary technicians to safely induce and maintain anesthesia in foals as well as recover them from anesthesia.

**References**


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1. Shortly after birth, a foal’s foramen ovale and ductus arteriosus close because of an increase in PaO₂ and a decrease in
   a. progesterone.  c. acetylcholine.  
   b. oxytocin.  d. prostaglandins.
2. Which of the following is a common MAP in a foal younger than 1 week?
   a. 30 to 40 mm Hg  c. 60 to 70 mm Hg 
   b. 40 to 50 mm Hg  d. 70 to 80 mm Hg
3. With the first few weeks of life, a foal’s MAP should gradually increase to a normal adult level of ___________ mm Hg.
   a. 30 to 40  c. 70 to 80 
   b. 40 to 50  d. 90 to 100
4. Which drug with mixed inotropic and chronotropic properties may be used to treat hypotension in foals?
   a. epinephrine  c. dobutamine 
   b. ephedrine  d. atropine
5. Which solution should be administered to anesthetized foals to maintain an adequate glucose level?
   a. 2.5% to 5% dextrose solution 
   b. Normosol-R (Abbott Laboratories) 
   c. PlasmaLyte 56 (Baxter Corporation) 
   d. lactated Ringer’s solution
6. An acceptable PaCO₂ level in an anesthetized foal is ___________ mm Hg.
   a. 25 to 35  c. 45 to 65 
   b. 35 to 55  d. 65 to 75
7. Because ___________ may cause cardiovascular depression in neonatal foals, this drug should be avoided.
   a. propofol  c. diazepam  
   b. ketamine  d. xylazine
8. Warmed crystalloid fluids are most commonly administered to anesthetized foals at a rate of ___________ mL/kg/hr.
   a. 1 to 2  c. 10 to 20 
   b. 5 to 10  d. 20 to 30
9. Which ECG abnormalities can appear with uroperitoneum?
   a. bradycardia and increased duration of the QRS complex  
   b. tachycardia and increased duration of the QRS complex 
   c. bradycardia and decreased duration of the QRS complex 
   d. tachycardia and decreased duration of the QRS complex
10. Equine neonates with an IgG level of ___________ mg/dL require a plasma transfusion.
    a. <400  c. <600  
    b. <500  d. <800