ANESTHETIC CONSIDERATIONS FOR EQUINE COLIC
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INTRODUCTION
Equine colic is most commonly associated with pathology of the gastrointestinal (GI) system but may be caused by several other non-GI disease processes. These cases can present with widely varying degrees of severity and dysfunction. Treatment will depend upon the underlying cause of the colic, ranging from simple analgesic therapy and time to immediate aggressive therapy and surgical intervention. It is the latter group that poses the greatest difficulty for the veterinary practitioner and is at greatest risk of serious morbidity and mortality. Even under ideal circumstances horses presenting for routine elective procedures are at greater risk of mortality associated with general anesthesia than that for small animal patients and humans. The risk of anesthetic mortality involving routine procedures ranges from 0.6% to 1.8% and increases to 5% when horses are systemically ill. The approximate risk of mortality associated with anesthesia in routine small animal cases and humans are 0.1% and 0.01% respectively. Although the risks of anesthetic complications in equine colic patients are considerable, a thorough preoperative evaluation and treatment plan can considerably reduce this risk.

PRE-OPERATIVE CONCERNS AND INITIAL STABILIZATION
The anesthetist should work in conjunction or be directly involved with the initial examination of the horse. The anesthetist should carefully review the history (including duration of signs and treatments administered), physical exam findings, laboratory data and suspected lesion. All may impact the anesthetic protocol. Pain, abdominal distension, dehydration, cardiovascular and respiratory compromise, acid-base, electrolyte, and blood gas abnormalities are commonly present in these horses, and should be addressed prior to anesthesia.

PAIN MANAGEMENT
Many equine colic’s can be so painful that they are unmanageable, and dangerous to themselves and those around them. Pain can be managed with the use of NSAID’s (flunixin meglumine), α-2 agonists (xylazine, romifidine, medetomidine, detomidine) and opioids (butorphanol, morphine). Flunixin is commonly used after an initial assessment of the horse, and is a long acting and potent GI analgesic; it may also have some anti-endotoxic effects that could be beneficial in some patients. However, the practitioner should be aware that the long duration of effect may mask signs of progressing disease and that adverse side effects such as GI ulceration and decreased renal blood flow are possible. This is not to say analgesics should be withheld. In fact, appropriate pain management in conjunction with carefully re-evaluation of the horse will likely improve overall outcome by decreasing the negative neuroendocrine effects associated with pain. Alpha-2 agonists are also commonly used. They are potent visceral analgesics, but are associated with undesirable cardiovascular effects (reduction in cardiac output). The undesirable effects do not outweigh the benefits of using these drugs. However, it is prudent to use the lowest controlling dose and a drug of appropriate duration. Xylazine is recommended as the first line treatment for pain in the equine colic. It has a short analgesic duration (15-45 minutes) and allows frequent re-assessment of the horse. In addition the drugs’ negative cardiovascular effects are of shortest duration, and this may be an advantage if immediate anesthesia and surgery are required. There are some concerns that long lasting α-2 agonists may mask signs of a worsening colic, delaying treatment and aggravating the pathology. However, if a horse must be shipped for several hours to a referral center, detomidine may be an appropriate option. Butorphanol is an excellent choice as an adjunct to α-2 agonist sedation and analgesia. Butorphanol is a good visceral analgesic, has minimal cardiovascular effects and significantly potentiates the action of α-2 agonists. Increased ataxia is occasionally seen using an opioid and α-2 agonist combination.

ABDOMINAL DISTENSION
Abdominal distension associated with equine colic not only contributes to pain but may also impede respiratory and cardiovascular function. A markedly distended abdomen will impede diaphragmatic contraction and limit further chest wall expansion required for normal inspiration. Abdominal distension may also hinder venous return to the heart. Nasogastric decompression and or percutaneous trocharization may be indicated prior to inducing anesthesia.

HYDRATION STATUS
Hydration status should be assessed first by the physical exam and then supported by the hematocrit, total protein and other laboratory findings. Packed cell volumes (PCV) greater than 45% in horses presented for surgical colic have been correlated with significant increases in mortality. It should be noted that it is not uncommon to see a markedly dehydrated horses with an elevated PCV (>50%) and a normal to low TP. In the authors’ experience, this is often associated with significant GI inflammation and necrosis with “third” space protein loss. The anesthetist should anticipate a need for colloid therapy in these horses and may consider incorporating them into the initial rehydration plan.

CARDIOVASCULAR FUNCTION
The cardiovascular function may be severely compromised in horses presenting with colic as a result of dehydration and hypovolemia. Some horses may present moribund or with clinical signs suggestive of 8-10% dehydration. These horses require aggressive IV fluid therapy using crystalloids, colloids, hypertonic crystalloids or some combination of the three. Crystalloids (balanced electrolyte solutions) are frequently chosen as the initial resuscitation fluids. Crystalloid fluid rates as high as 45 ml/kg/hr are well tolerated in adult horses. In horses showing evidence of “third” space protein loss, use of a colloid such as dextran (40 or 70), hetastarch, and polymerized bovine hemoglobin can be considered. Equine plasma can also be considered for colloid support. Unfortunately, the amount of protein in collected plasma is often less than optimal so large volumes are required; it is costly and in many practices may not be readily available. Ideally, the entire volume deficit is replaced prior to induction of general anesthesia. In many cases this involves fluid volumes in excess of 40 L, which if given at
standard rates, may take more than an hour to administer. This delay can be potentially life threatening. Another option to quickly volume resuscitate a hypovolemic animal, is to use hypertonic solutions such as 7% saline at a dose of 2-4 ml/kg. It must be remembered that the cardiovascular stabilizing effects of hypertonic saline persist for only 30-60 minutes, and will necessitate continued volume resuscitation during this time to prevent recurrence of signs associated with hypovolemia. Ideally, hypertonic solutions are administered within 15 minutes of induction to take full advantage of the volume expanding effects during the induction. Placing a second IV catheter either prior to, or immediately after induction is recommended, as intraoperative fluid administration and support may require the use of several IV solutions simultaneously.

RESPIRATORY FUNCTION AND BLOOD GASES
Although primary respiratory dysfunction is not commonly associated with equine colic, a thorough search for evidence of underlying or low-grade respiratory disease should be undertaken. Most respiratory abnormalities are secondary to the primary abdominal pathology or in some instances may be iatrogenic and associated with treatment. As already mentioned, a markedly distended abdomen may interfere with the mechanics of respiration. Other causes of respiratory dysfunction may include accidental aspiration of water, feed material or medications used during nasogastric intubation and stomach lavage. Arterial blood gas analysis is ideal for assessing compromises in gas exchange but is frequently unavailable. Ideally P\textsubscript{a}O\textsubscript{2} should be greater than 60 mmHg and P\textsubscript{a}CO\textsubscript{2} should be between 35-45 mmHg.

ACID-BASE BALANCE AND ELECTROLYTES
Most moderately compromised colic patients will have a metabolic acidosis caused by anaerobic metabolism and lactic acid production secondary to hypovolemia and hypoperfusion of tissues. Treatment usually involves adequate rehydration, but if the blood pH approaches 7.1, sodium bicarbonate should be considered. Ideally the blood pH should be greater than 7.2, as this will help minimize the myocardial depressant and arrhythmogenic effects associated with a low pH. Electrolyte abnormalities may also contribute to changes in acid-base balance, and attempts should be made to correct the observed abnormalities. Special attention should be given to the ionized Ca\textsuperscript{2+} levels as changes in calcium flux into myocardial cells may be responsible for the cardio-depressive effects of the inhalant anesthetics. It has been shown that calcium gluconate infusion during inhalant anesthesia can improve cardiovascular performance.

ANESTHETIC MANAGEMENT INDUCTION
Induction techniques rely heavily upon the use of some combination involving acepromazine, \(\alpha\)-2 agonists, diazepam, butorphanol, guaifenesin and thiopental or ketamine. Less commonly used agents include propofol, thiamyllal and tiletamine-zolazepam. No single induction technique has been shown to be clearly superior over the others, and it is recommended to use the technique the anesthetist is most familiar with. In the authors' opinion, a true multi-modal approach works best by capitalizing on the additive effects of each agent while reducing the negative effects of any single agent. In general, one should attempt to use those drugs with minimal negative cardiopulmonary side effects. This author's routine protocol includes: the lowest effective dose of xylazine (0.1-0.5 mg/kg), butorphanol (0.01-0.03 mg/kg) followed by guaifenesin (50-100 mg/kg) to effect, and ketamine (2 mg/kg) combined with diazepam (0.04 mg/kg). Alternatively, if guaifenesin is not available, a higher dose of diazepam (0.1 mg/kg) can be used. The vasodilatory effects of acepromazine may not be desirable in an already hypovolemic animal and it is therefore generally avoided. Low dose xylazine is chosen as the sedating \(\alpha\)-2 agonist because of its relatively short duration of action, and to minimize the negative cardiopulmonary side effects. Using such low doses (0.1-0.2 mg/kg) of xylazine may result in an induction associated with increased muscle tone and "twitchiness", however, in the authors experience; this has not been associated with any difficulties.

MAINTENANCE
Maintenance of anesthesia is generally accomplished using an inhalant anesthetic although several total intravenous anesthetic (TIVA) protocols have been described. Regardless of the technique employed supplemental oxygen using a cuffed endotracheal tube should be provided. Tracheal intubation and inflation of the endotracheal tube cuff is probably best done in sternal recumbency if the induction facilities allow such positioning. Regurgitation can occur when markedly distended horses are placed in lateral recumbency. Isoflurane and sevoflurane are the preferred inhalants as they cause less depression of cardiac output at equipotent doses than halothane in adult horses. However, isoflurane and sevoflurane do cause greater depression of respiratory rate than halothane and this may be a consideration in practices lacking a large animal ventilator. Sevoflurane may improve the quality of recoveries after anesthesia but this has not yet been clearly demonstrated in colic horses undergoing an exploratory laparotomy.

Although opioid analgesics have not been shown to consistently decrease inhalant requirements in horses, they are often used as anesthetic adjuncts during maintenance of anesthesia. Butorphanol is commonly used as an intraoperative analgesic and is administered as needed at 0.02-0.04 mg/kg. Butorphanol can be expected to last for about 2 hours. \(\mu\)-agonist opioids can also be considered for use, but there has traditionally been concern that they may decrease gastrointestinal motility. Ketamine and lidocaine infusions have both been studied in anesthetized horses and there is evidence that the inhalant sparing effect may improve cardiopulmonary function. Side effects of these infusions appear to be minimal but they have not been evaluated for use in colic patients and the impact on recovery quality is not known. Lidocaine infusions are frequently used postoperatively to prevent or treat ileus and early intraoperative use may improve anesthetic management and postoperative recovery.

INTRA-OPERATIVE SUPPORT AND MONITORING SUPPORT
Adequate respiratory and cardiovascular support are extremely important for optimal outcome of anesthesia. Respiratory support using intermittent positive pressure ventilation (IPPV) is recommended even though studies show that IPPV to eucapnia may aggravate hypotension. This effect can be minimized by appropriate cardiovascular support. In colic horses, respiratory compromise resulting
from prolonged dorsal recumbency can be further exacerbated by abdominal distension. Guidelines for frequency and tidal volume range from 4-10 breaths per minute and 10-18 ml/kg, respectively. Larger tidal volumes should be expected for a fit thoroughbred versus an overweight non-athletic horse. In general, peak airway pressures should not exceed 30 cmH2O, inspiration time should be limited to 3 seconds in duration, and the inspiratory:expiratory ratio should be 1:2 or greater to limit the cardiovascular impact of IPPV. In patients with marked abdominal distension, peak airway pressures in excess of 50 cmH2O may be required to ventilate the horse. Ideally, PaO2 should be greater than 100mmHg (SpO2 greater than 97%); increases above this level will do little to increase the total amount of oxygen carried in the blood. Therefore, extreme manipulations such as large increases in tidal volume or excessively long inspiratory times that may predispose the animal to lung barotrauma/volutrauma or additional cardiovascular depression are ill advised. However, it is important to be aware that an animal with PaO2 pressures should not exceed 30 cmH2O, inspiration time should be limited to 3 seconds in duration, and the inspiratory:expiratory ratio should be 1:2 or greater to limit the cardiovascular impact of IPPV. In patients with marked abdominal distension, peak airway pressures in excess of 50 cmH2O may be required to ventilate the horse. Ideally, PaO2 should be greater than 100mmHg (SpO2 greater than 97%); increases above this level will do little to increase the total amount of oxygen carried in the blood. Therefore, extreme manipulations such as large increases in tidal volume or excessively long inspiratory times that may predispose the animal to lung barotrauma/volutrauma or additional cardiovascular depression are ill advised. However, it is important to be aware that an animal with PaO2

hemodynamic support often involves the use of sympathomimetic drugs but the importance of continued fluid resuscitation should not be dismissed, and should carry on from the preoperative resuscitation. Standard intra-operative crystalloid fluid rates in horses are 5-10 mL/Kg/hr; colloids are usually given at 1/3 this rate. Evidence of continued need for aggregative fluid therapy may be an increasing PCV/TP, tachycardia, dampening of the pressure wave in association with ventilation, hypotension, pale dry mucous membranes, and a decreased capillary refill time. Vigilance, experience and good clinical judgment are all required to assess ongoing fluid requirements in equine patients but rough guidelines based on the estimates of initial dehydration, ongoing losses and surgical maintenance can help direct therapy. For example, a 500 kg horse that admits with clinical signs consistent with 6% dehydration and minimal on-going losses after 2 hours of surgery should have received roughly 35-40 L of crystalloid (6% X 500kg = 30L plus surgical maintenance 5-10mL/Kg/hr X 500kg X 2hr = 5000-10000 mL).

Dobutamine (1-5 µg/kg/min) is the most effective sympathomimetic for maintaining blood pressure and cardiac output in the horse. Dobutamine is administered as an infusion and this necessitates additional attention to “IV line management”. Dobutamine can be diluted with 5% dextrose or 0.9% saline to 0.5-1.0 mg/mL solution to facilitate administration. Inadvertent IV boluses of dobutamine, although unlikely to be fatal, may confound interpretation of the monitored parameters and lead to inappropriate treatment decisions. Tachycardia and other arrhythmias can be seen with dobutamine doses in the upper end of the dose range, although in some animals this effect can be seen even when using extremely low doses.

Ephedrine (0.1-0.6 mg/kg IV) is also used to support blood pressure and cardiac output. Ephedrine has the advantages of bolus administration and a prolonged effect (30-60 minutes). Since some of ephedrine’s effects rely on the release of endogenous catecholamines, it may be less effective in an already catecholamine depleted animal. Additionally, it is more difficult to titrate the ephedrine “to effect” using bolus administration. Other sympathomimetics such as dopamine, doxepamine, methoxamine, phenylephrine and norepinephrine are rarely if ever used or indicated.

As already mentioned, infusions of Ca++ gluconate (0.1-0.4 mg/kg/min) may be beneficial in maintaining blood pressure and cardiac output. Additionally, some colic horses have low serum calcium levels and may benefit from calcium administration regardless of the need for cardiovascular support.

MONITORING

Monitoring the cardiovascular, respiratory and central nervous systems is essential for successful anesthesia. In colic cases minimal monitoring requirements include invasive blood pressure (IBP), ECG, pulse oximetry or blood gas analysis, periodic PCV and TP estimations and vigilant assessment of clinical signs associated with depth of anesthesia. Invasive blood pressure can easily be accomplished and should not be neglected in critical colic cases. Expensive equipment facilitates IBP but it can also be done using nothing more than an intra-arterial catheter, a long length of IV tubing or pressure manometer, a three-way stopcock, and a flush syringe. The ECG is typically placed in a base-apex configuration and is used to monitor heart rate and rhythm. Early pulse oximeters had a high failure rate when used on equine patients, but several more recent models have been tested and validated for use in horses. Pulse oximeters provide a continuous non-invasive method of monitoring hemoglobin saturation, a parameter of critical importance in equine colic patients. PCV and TP concentrations can help guide fluid therapy when interpreted properly. Additional monitoring might include capnography or capnometry (end-tidal CO2 or ETCO2), airway gas concentrations (O2 and inhalant) and periodic blood gas analysis. The ETCO2 value is reflective of arterial CO2 (PaCO2). Actual PaCO2 is usually 10-15 mmHg greater than ETCO2. Because ETCO2 is reflective of PaCO2 this value gives an estimation of the adequacy of ventilation.

RECOVERY

Recovery is a critical period in equine anesthesia. Complications occurring in this phase of anesthesia account for a significant amount of the morbidity and mortality associated with general anesthesia in equine patients. The equine colic patient is even more prone to complications in recovery as these horses are often exhausted at the time of presentation, and may have significant systemic changes associated with the primary lesion. The anesthetist should make every attempt to have all electrolyte (Ca++), acid base and hydration derangements corrected before placing the horse in the recovery stall to provide the most favorable conditions for recovery. In general, all recovering horses should be provided with an appropriate recovery facility with suitable padding and footing, oxygen supplementation and constant observation. Ideally, a horse should remain recumbent until it is fully awake and strong enough to stand without risk of injury. This is often accomplished by using a small sedative dose of xylazine (0.01-0.02 mg/kg) and by ensuring the recovery room is dark and quiet, and that the horse is not disturbed or aroused. A sedative dose of xylazine is not always required, and in some instances may be undesirable for extremely weak and debilitated animals.
Providing adequate analgesia and comfort should also help improve recovery by preventing early attempts to stand. Hypoxemia is well documented during the recovery period in horses. The use of supplemental oxygen is important during recovery to ensure adequate oxygen delivery to tissues involved in attempts to stand. It is likely that the presence of hypoxemia could increase CNS arousal and may lead to early and un-coordinated attempts to stand. Oxygen can be supplemented using oxygen insufflation at 10-15 L/min or via a demand valve device that delivers 100% at flow rates up to 200 L/min. Oxygen supplementation can be provided via a nasotracheal tube, orotracheal tube or by a tube placed through the nose into the nasopharynx. No one technique of oxygen supplementation has been shown to be superior to others and the technique chosen is most often due to personal preference. Some facilities will “hand recover” weak and sick horses. Some will remain in the recovery stall with the horse and directly assist the horse to standing. Others use assisting techniques involving ropes either from within or outside the recovery stall. Some of these techniques require considerable skill and can be potentially dangerous for the personnel involved.

POST-OPERATIVE MANAGEMENT

Although some may consider that the anesthetist’s role ends when the case is fully recovered, it is important that anesthetists continue to follow their surgical colic cases. It provides a collaborative opportunity for both the anesthetist and surgery team to share expertise; particularly in areas such as pain management and fluid, electrolyte and metabolic therapy. Complications that may be related to a particular anesthetic or recovery technique may also be recognized in the post-operative period. This provides useful information regarding future case management and early detection of potential problems.