Peripartum Asphyxia Syndrome in Foals

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Peripartum asphyxia produces hypoxic ischemic encephalopathy (HIE), ischemic renal failure, and varying degrees of necrotizing enterocolitis (NEC). Diagnosis relies on transabdominal ultrasonography of the fetoplacental unit, placental and neonatal foal examination, and immediate postpartum assessment of creatinine and presuckle glucose in the foal. Patient survival depends on management of CNS, gastrointestinal, and renal dysfunction. Author’s address: Mid Atlantic Equine Medical Center, 40 Frontage Road, Ringoes, NJ 08551. © 1999 AAEP.

1. Introduction

Reynolds first described a syndrome in newborn foals characterized by unusual behavioral abnormalities in 1930.1 Affected foals displayed symptoms that included barking like dogs, clonic/tonic seizures, aimless wandering, central blindness, loss of suckle, and loss of affinity for the dam. During the next three decades similar behavioral disturbances were described in greater detail. A variety of names were used to describe affected foals based on the most salient neurologic deficits: barkers, wanderers, convulsives, and dummies. The condition was usually associated with rapid, outwardly uncomplicated deliveries and the development of signs within 24 hours postpartum. In 1968 Rossdale used the term “neonatal maladjustment syndrome” (NMS) to describe these foals with behavioral disturbances and disruption of normal adaptive processes required for survival.2 Hypoxic ischemic brain damage was the suspected cause of NMS. Trauma to the chest and heart leading to circulatory disturbances in the CNS and premature clamping of the umbilical cord preventing the transfer of a significant volume of blood from the placenta to the foal were some of the peripartum events associated with this condition. Respiratory distress was occasionally observed in affected foals.

Neurologic dysfunction remained the hallmark of NMS for the next 25 years. When the heart and lungs were affected, foals also showed tachycardia, respiratory distress, hypoxemia, and acidemia. Necropsy of affected foals revealed a confusing array of CNS lesions that included subdural, epidural, subarachnoid, parenchymal, and nerve root hemorrhages of the brain and spinal cord, and varying degrees of CNS edema and necrosis. Occasional hepatic and renal lesions were noted. Survival rates among NMS foals remained approximately 50%.3

During the last 12 years it has become increasingly evident that many foals with NMS experience varying degrees of multisystemic effects of hypoxia. A more appropriate term is peripartum asphyxia syndrome (PAS), which encourages recognition of the renal, gastrointestinal, cardiopulmonary, endocrine, as well as neurologic and behavioral disturbances that can occur in these foals.
2. Asphyxia

Asphyxia is the result of impaired oxygen delivery to cells and usually results from a combination of hypoxemia (decreased oxygen concentration in the blood) and ischemia (decreased tissue perfusion). Pure hypoxemia implies a decrease in oxygen concentration in the blood with preservation of blood flow, which allows organs to respond by increasing their efficiency of extracting oxygen from the circulation. Ischemia is far more devastating and results in anaerobic metabolism, increased lactate concentrations, intracellular acidosis, and is a preamble for reperfusion injury.

In utero the fetus adapts to a relatively hypoxic environment by increased oxygen affinity of fetal hemoglobin, increased ability to extract oxygen from the blood and a greater tissue resistance to acidosis. Fetal compensatory mechanisms against increasing asphyxia include bradycardia, decreased oxygen consumption, anaerobic glycolysis, and redistribution of blood flow with preferential perfusion of the brain, heart and adrenal glands at the expense of circulation to kidneys, gut, liver, lungs, and muscle. The extent of tissue injury depends on whether the asphyxial insult is acute or chronic, partial or complete, and whether the neonate is premature or full term.

In women, chronic hypoxia is associated with accelerated placental aging with loss of placental nutritive function and a reduction in amniotic fluid (oligohydramnios). Oligohydramnios is produced by redistribution of cardiac output and decreased blood flow to lungs and kidneys. Production of fetal urine and lung liquid, major constituents of amniotic fluid in humans, are accordingly decreased. Oligohydramnios has been identified in a mare with suspected placental dysfunction and resulted in a foal with signs of severe hypoxia that included seizures, opisthotonus, unresponsive hypotension, and fetal reflexes disappearing first. Fetal reflexes also slow fetal growth in a pattern that reflects asphyxia-induced redistribution of blood flow. Brain and bone are spared, whereas gut, liver, and fat are not. The result is a fetus with a small body and large head. This form of in utero growth retardation (IUGR) is termed disproportionate. Although growth is slowed, maturation of fetal organs is enhanced, most likely the result of in utero stimulation of the fetal adrenal gland and endogenous steroid production. Foals with signs of IUGR have been associated with small placentas, post-term pregnancies, advanced maternal age, and twinning.

During severe in utero hypoxia there is sequential loss of fetal reflexes with the most oxygen-demanding fetal activities disappearing first. Fetal reflexes are lost in the following order: (1) fetal heart rate reactivity (the ability to increase heart rate in response to fetal activity), (2) fetal breathing, (3) generalized fetal movements, and (4) fetal tone. These biophysical events, in addition to amniotic fluid volume estimation and placental integrity, can be evaluated in the late pregnant mare using transabdominal ultrasonography. Fetal foal hypoxia has been associated with placental separation, placental edema, placentitis, hydrops, and twinning.

3. Periparturient Events

PAS can result from any event that impairs uteroplacental perfusion prepartum or intrapartum, or disrupts normal distribution of blood flow postpartum. PAS has been associated with normal deliveries, dystocias, induced deliveries, Cesarean sections, placental insufficiency and the birth of small, underweight, maladapted foals. PAS results in varying degrees of asphyxia with or without sepsis. Meconium staining of the foal, fetal fluids or placenta is associated with fetal distress and hypoxia. Hypoxia results in intestinal ischemia, hyperperistalsis, anal sphincter relaxation, and in utero passage of meconium. Fetal meconium aspiration results in varying degrees of respiratory compromise including pulmonary hypertension, chemical pneumonitis, airway obstruction, regional lung atelectasis, and surfactant dysfunction. Twinning can be associated with placental insufficiency and growth retardation. Acute hypoxia can occur during a difficult delivery with prolonged exposure of the second twin to uterine contractions and disruption of blood flow and oxygen delivery.

Severe maternal illness accompanied by anemia, hypoproteinemia, and endotoxemia can alter uteroplacental blood flow. Post-term pregnancies have been associated with varying degrees of placental insufficiency and the birth of small, underweight, maladapted foals. Post partum, severe neonatal cardiopulmonary disease can contribute to hypoxic, ischemic tissue damage. Examples of such conditions include pneumonia, atelectasis, surfactant dysfunction, cardiac insufficiency due to septic shock, persistent fetal circulation, and heart defects.

4. Clinical Signs and Pathophysiology

Clinicopathologic conditions associated with PAS are listed in Table 1.

A. Central Nervous System

Asphyxia produces hypoxic ischemic encephalopathy (HIE) associated with hemorrhage, edema, and necro-
s. Mild asphyxia produces transient tissue ischemia with potentially reversible damage. Prolonged ischemia results in disruption of tight junctions in the capillary endothelium and leakage of osmotic agents and fluid into surrounding brain interstitium resulting in vasogenic edema. Brain necrosis occurs and is accompanied by increased intracranial pressure, progressive brain swelling, reduced cerebral blood flow, and exacerbation of existing ischemia.

An important mediator of ischemic tissue damage is the fast excitatory neurotransmitter glutamate. At high extracellular concentrations, glutamate acts as a neurotoxin and mediates opening of ion channels that permit sodium to enter cells followed by an influx of chloride ions and water resulting in osmotic lysis and immediate neuronal death. Glutamate also mediates delayed cell death by provoking calcium influx through depolarization-induced opening of calcium channels and by direct stimulation of N-methyl-D-aspartate (NMDA) receptors that open additional calcium channels. High intracellular levels of free calcium result in activation of lytic enzyme systems, generation of free radicals, and impaired mitochondrial function resulting in delayed neuronal death. NMDA and calcium antagonists are being investigated to help reduce delayed ischemic brain injury.

Additional brain injury occurs as a result of repeated seizures, which are common during severe encephalopathy. Repeated seizures cause brain injury through (1) hypoventilation and apnea resulting in hypoxemia and hypercapnea, (2) elevation in arterial blood pressure and cerebral blood flow, (3) progressive neuronal injury due to excessive release of excitatory amino acids such as glutamate, and (4) depletion of the brain’s limited energy stores to support seizure activity.

Neonatal foals suffering from HIE display a wide spectrum of neurologic signs that include jitteriness, hyperalertness; stupor, somnolence, difficult to arouse; lethargy, hypotonia; clonic seizures; extensor rigidity, hypertension; subtle seizures, tonic posturing; coma, death; aimless wandering, head pressing, loss of affinity for the dam, inability to find the udder; abnormal vocalization (barking, high pitched cry); loss of suckle, dysphagia, decrease tongue tone, odontoprisis; central blindness, anisocoria, mydriasis, nystagmus, eye deviation; head tilt, head and neck turn; irregular respiration, apnea, abnormally slow respiratory rate; and proprioceptive deficits, spastic dysmetric gait.

Foals with HIE exhibit a variety of seizure-like activities. Jitteriness is associated with mild hypoxia and is not a true seizure but rather a movement disorder consisting of tremors that can be stopped by gentle restraint. The tremors are often rhythmic and of equal rate and amplitude. Subtle seizures are called motor automatisms and are characterized by paroxysmal events including eye blinking, eye deviation, nystagmus, eye deviation; head tilt, head and neck turn; irregular respiration, apnea, abnormally slow respiratory rate; and proprioceptive deficits, spastic dysmetric gait.

Table 1. Clinicopathologic Conditions Associated with PAS

<table>
<thead>
<tr>
<th>Organ System</th>
<th>Clinical Signs</th>
<th>Laboratory Findings</th>
<th>Pathology Lesions</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNS</td>
<td>Hypotonia, hypertonia, seizures, coma, loss of suckle, proprioceptive deficits, apnea</td>
<td>Increased ICP, increased BBB permeability and albumin quotient</td>
<td>CNS hemorrhage, edema, ischemic necrosis</td>
</tr>
<tr>
<td>Renal</td>
<td>Oliguria, anuria, generalized edema</td>
<td>Azotemia, hyponatremia, hypochloremia, abnormal urinalysis</td>
<td>Tubular necrosis</td>
</tr>
<tr>
<td>Gastrointestinal</td>
<td>Colic, ileus, abdominal distension, bloody diarrhea, gastric reflex edema</td>
<td>Occult blood (+) feces and reflux, pneumonia intestinalis</td>
<td>Ischemic mucosal necrosis, enterocolitis, ulceration</td>
</tr>
<tr>
<td>Respiratory</td>
<td>Respiratory distress, tachypnea, dyspnea, rib retractions</td>
<td>Hypoxemia, hypercapnea, respiratory acidosis</td>
<td>Hyaline membrane disease, atelectasis, meconium aspiration, pulmonary hypertension</td>
</tr>
<tr>
<td>Cardiac</td>
<td>Arrhythmia, weak pulses, tachycardia, edema, hypotension</td>
<td>Hypoxemia, elevated myocardial enzymes</td>
<td>Myocardial infarcts, valvular insufficiency, PFC</td>
</tr>
<tr>
<td>Hepatic</td>
<td>Icterus, abnormal mentation</td>
<td>Hyperbilirubinemia, elevated liver enzymes</td>
<td>Hepatocellular necrosis, biliary stasis</td>
</tr>
<tr>
<td>Endocrine: adrenals, parathyroids</td>
<td>Weakness, apnea, seizures</td>
<td>Hypocortisolemia, hypocalcemia</td>
<td>Necrosis, hemorrhage</td>
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IN DEPTH: PEDIATRICS

hyponatremia, hypernatremia, hyperosmolality (e.g., hyperlipemia, hyperglycemia), severe azotemia, hepatocencephalopathy; (2) infectious conditions: septic meningitis, septicemia/endotoxemia, EHV1 infection; (3) malformation: hydrocephalus, agenesis of the corpus callosum, vertebral and spinal cord and malformations, cerebellar abiotrophy, occipitoatlantoaxial malformation; (4) cranial or vertebral trauma; and (5) toxins.

If severe metabolic derangements, infections, and congenital defects are ruled out, then asphyxia is the most likely cause of the foal's neurologic deficits. Normal serum chemistries help rule out metabolic disturbances. A normal leukogram or the absence of severe leukopenia, neutropenia, and toxic neutrophil changes help rule out septic conditions. Cerebrospinal fluid analysis is indicated if septic meningitis is a possible differential. Septic meningitis produces an increased nucleated cell count, protein concentration, and IgG index in the CSF. Hypoxic brain damage may result in an increased albumin quotient in the CSF compatible with increased blood brain barrier permeability.

Other diagnostic aids that have enjoyed limited use in the horse include cranial ultrasonography, computed tomography (CT), magnetic resonance imaging (MRI), EEGs, and auditory evoked brainstem potentials.

B. Renal Function
Decreased renal perfusion occurs during asphyxia as a result of redistribution of fetal cardiac output. In infants renal damage has proven to be a sensitive indicator of even mild peripartum asphyxia. Clinical signs of renal ischemic damage include oliguria (<1 ml urine/kg/h), peripheral edema, elevated concentrations of serum creatinine and urine GGT, and electrolyte disturbances such as hypocalcemia, hyponatremia, and hypochloremia due to renal tubular damage.

C. Gastrointestinal Function
Hypoxia results in reduced mesenteric and splanchnic blood flow and varying degrees of intestinal ischemia. The most severe form of intestinal dysfunction is NEC. During gastrointestinal ischemia, mucosal cell metabolism diminishes and production of the protective mucus layer ceases, allowing proteolytic enzymes to begin autodigestion of the mucosal barrier. Bacteria within the lumen can then colonize, multiply, and invade the bowel wall. Intramural gas is produced by certain species of bacteria and pneumatosis intestinalis develops. Possible complications include intestinal rupture, pneumoperitoneum, severe bacterial peritonitis, and septicemia. Three conditions are associated with development of NEC: (1) ischemic, hypoxic gut injury, (2) presence of intraluminal bacteria, and (3) enteral feeding. Clinical signs associated with varying degrees of hypoxic, ischemic gut injury include ileus, gastric reflux, colic, lethargy, abdominal distension, and diarrhea. Reflux and feces may be positive for blood. Generalized sepsis often accompanies NEC. The radiographic hallmark of NEC is pneumatosis intestinalis characterized by linear or cystic submucosal gas accumulation within the bowel wall. In foals transabdominal ultrasonography has been used to identify focal bowel wall thickening and intramural gas accumulation that appears as sharp white echoes. As a result of varying degrees of intestinal dysmotility, some foals develop intussusceptions that can be visualized with ultrasound.

D. Cardiopulmonary Function
The response of pulmonary vasculature to hypoxia and acidemia includes (1) increased pulmonary vascular resistance, (2) pulmonary hypertension, (3) increased atrial pressure, and (4) persistent right-to-left flow of blood across fetal pathways (e.g., patent ductus arteriosus, foramen ovale). When persistent fetal circulation (PFC) patterns exist, hypoxemia is exacerbated. During asphyxia-induced pulmonary vasoconstriction substrate delivery to the pneumocytes is impaired and surfactant production decreases with secondary pulmonary atelectasis. Asphyxia may also affect the breathing center directly resulting in abnormal breathing patterns, including prolonged apnea.

If asphyxia induces in utero passage of meconium, then the fetus may aspirate meconium. Meconium can cause mechanical obstruction of airways resulting in suffocation or regional lung atelectasis. Partial obstruction produces a ball-valve phenomenon with distal air trapping, ventilation–perfusion mismatching, alveolar overdistension and possible rupture, interstitial emphysema, and pneumothorax. Meconium also induces chemical pneumonitis accompanied by alveolar collapse and edema.16 The free fatty acids in meconium displace surfactant resulting in additional atelectasis and decreased lung compliance.13

Adverse effects of asphyxia on myocardial function include (1) reduced myocardial contractility, (2) left ventricular dysfunction, (3) tricuspid valve insufficiency, and (4) cardiac failure. As a result of cardiac insufficiency the foal may develop systemic hypotension, further impairment of renal blood flow, and decreased pulmonary perfusion. Foals with cardiopulmonary dysfunction may show signs of respiratory distress with tachypnea and dyspnea, tachycardia, hypotension, and murmurs. Cardiac isoenzymes may be increased. If pulmonary hypertension develops, thoracic radiographs show diminished vascular markings due to pulmonary hypoperfusion. Surfactant dysfunction produces diffuse lung atelectasis and a diffuse reticulogranular parenchymal pattern with air bronchograms. Meconium aspiration may produce perihilar infiltrated and focal atelectasis. Echocardiography helps identify arrhythmias.
E. Hepatic and Endocrine Function
Hypoxic liver damage produces an increase in hepatocellular and biliary enzymes. Affected neonates are usually icteric. Impaired hepatic function renders the neonate more susceptible to alteration in glucose homeostasis and can result in decreased hepatic defense mechanisms and increased susceptibility to sepsis. Endocrine organ damage associated with hypoxia includes adrenal gland hemorrhage and necrosis with hypocortisolemia. Parathyroid damage may result in hypocalcemia. Pancreatic injury and abnormal insulin activity can occur.

5. Guidelines for Therapy
Specific drug dosages used in the treatment of different clinical conditions associated with PAS are presented in Table 2.

A. CNS Dysfunction
Anticonvulsive therapy is required to control seizures. Diazepam is used initially to stop seizures quickly because of its rapid onset of action. Due to its short duration, diazepam should be followed by phenobarbital to control severe or recurrent seizures. Phenobarbital should be given slowly to minimize respiratory depression. Foals receiving phenobarbital should have their body temperature, blood pressure, and respiratory rate monitored. Xylazine should be avoided since it can cause transient hypertension with exacerbation of CNS hemorrhage. Avoid acepromazine since it lowers the seizure threshold. Cerebral edema occurs in some HIE foals. DMSO is administered to help reduce brain swelling and intracranial pressure as well as decrease inflammation and platelet aggregation. DMSO has mild antibacterial and antifungal properties and is a free radical scavenger. The osmotic diuretic, mannitol, has been used to treat cerebral edema and to scavenge free radicals. Intravenous fluid administration should be conservative (5–7 ml/kg/h) and fluid balance monitored in anuric or oliguric patients to avoid exacerbation of cerebral edema. Controversy surrounds the benefits of glucose administration to neonates during the early post-hypoxic period. Possible benefits include a reduced incidence of CNS infarction, attenuated brain damage, and some degree of neuroprotection by stimulating insulin release and reducing glycolysis, free radical formation, and glutamate-mediated injury. However, hyperglycemia can augment hypoxic brain injury. It is best to avoid extremes in glucose concentration. Minimize self-trauma in foals with the application of leg wraps and soft head helmets and the use of padded stalls and fleece-covered beds.

B. Renal Dysfunction
Fluid therapy should be monitored closely to avoid overhydration and hyper- and hypo-osmolar states. Low levels of dopamine stimulate dopaminergic receptors and improve renal blood flow and urine production. Moderate doses also stimulate beta-1 receptors to increase heart rate and strength of contraction, which help improve renal perfusion by correcting mild cases of hypotension. High doses of dopamine stimulate alpha-1 receptors resulting in

<table>
<thead>
<tr>
<th>Organ System</th>
<th>Clinical Sign</th>
<th>Drug Therapy</th>
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<tbody>
<tr>
<td>CNS</td>
<td>Seizures</td>
<td>Diazepam: 0.11–0.44 mg/kg IV</td>
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<td>Phenobarbital: 2–10 mg/kg IV q 12 h; give slowly, monitor serum levels</td>
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<tr>
<td></td>
<td></td>
<td>Pentobarbital: 2–10 mg/kg IV</td>
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<tr>
<td></td>
<td>CNS edema</td>
<td>DMSO: 0.5–1.0 g/kg IV as 20% solution over 1 h; can repeat q 12 h</td>
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<td></td>
<td></td>
<td>Mannitol: 0.25–1.0 g/kg IV as 20% solution over 15–20 min; q 12–24 h</td>
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<tr>
<td>Renal</td>
<td>Oliguria, anuria</td>
<td>Dopamine infusion: 2–10 µg/kg/min; monitor blood pressure and pulse</td>
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<tr>
<td></td>
<td></td>
<td>Furosemide infusion: 0.25–2.0 µg/kg/h or 0.25–0.5 mg/kg IV q 1–6 h; monitor serum electrolytes and hydration status</td>
</tr>
<tr>
<td>Gastrointestinal</td>
<td>Ileus, GI distension</td>
<td>Mannitol: 0.5–1.0 g/kg IV as 20% solution over 15–20 min</td>
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<td>Dobutamine infusion: 2–15 µg/kg/min; use if cardiac dysfunction is contributing to hypotension and poor renal perfusion</td>
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<td></td>
<td>Ulcers</td>
<td>Cisapride: 10 mg PO q 6–8 h</td>
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<td>Metoclopramide: 0.25–0.5 mg/kg/h infusion q 6–8 h</td>
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<tr>
<td>Cardiac</td>
<td>Hypotension</td>
<td>Ranitidine: 5–10 mg/kg PO q 6–8 h, 1–2 mg/kg IV q 6–8 h</td>
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<td></td>
<td></td>
<td>Cimetidine: 15 mg/kg PO q 6 h; 6.6 mg/kg IV q 6 h</td>
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<td></td>
<td></td>
<td>Omeprazole: 4.0 mg/kg PO q 24 h</td>
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<tr>
<td>Respiratory</td>
<td>Hypoxemia</td>
<td>Dopamine infusion: 2–10 µg/kg/min</td>
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<tr>
<td></td>
<td>Apnea</td>
<td>Dobutamine infusion: 2–15 µg/kg/min</td>
</tr>
<tr>
<td>Endocrine system</td>
<td>Hypocortisolemia</td>
<td>Digoxin: 0.02–0.035 mg/kg PO q 24 h if cardiac failure is suspected</td>
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<tr>
<td>Immune system</td>
<td>FPT, leukopenia</td>
<td>Intranasal, humidified oxygen: 2–10 LPM</td>
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<td></td>
<td></td>
<td>Caffeine: loading dose: 10 mg/kg PO; maintenance dose: 2.5–3.0 mg/kg PO q 24 h</td>
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<td></td>
<td></td>
<td>ACTH (depot): 0.26 mg IM q 8–12 h</td>
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<td></td>
<td></td>
<td>Hyperimmune plasma: 10–20 ml/kg IV; monitor serum IgG and WBC</td>
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an increase in arterial pressure and a reduction in splanchnic blood flow. Renal and gastrointestinal perfusion are reduced, which is why high-dose dopamine administration should be avoided. Furosemide works synergistically with dopamine to promote diuresis. Serum electrolytes should be monitored during diuretic therapy.

C. Gastrointestinal Dysfunction

Ileus associated with hypoxic gut damage can result in bowel distension and colic. Nasogastric decompression relieves proximal gut distension. Enema administration stimulates distal colonic function and encourages passage of gas. Metoclopramide and erythromycin may improve gastric emptying and upper GI function. Cisapride and erythromycin have been used to stimulate small and large intestinal motility. Be certain to allow adequate time for healing of damaged bowel prior to using prokinetics in a compromised foal. Sonographic examination of the abdomen helps rule out the presence of intussusceptions and other obstructive lesions prior to administering motility modifiers. Severe large bowel distension may require percutaneous trocarization. This is an aseptic technique that involves introduction of a catheter with a stylet into the gas-distended viscus. Visual inspection of the abdomen or sonographic identification of a gas-distended colon and/or cecum chooses the site for trocarization. With the foal sedated and gently restrained in lateral recumbency, a 16- or 18-G catheter over a stylet is inserted aseptically into the distended viscus to provide direct decompression. The catheter is attached to an extension set. Decompression is evaluated by observing bubbles produced when the end of the extension tubing is held under a small volume of sterile water in a sterile container. A brief course of antibiotic therapy is instituted following the procedure to reduce the risk of peritonitis.

To reduce the risk of NEC, asphyxiated foals should have enteral feeding withheld until intestinal motility has returned. Reassuring signs include manure passage, normal borborygmi, and stable vital signs (temperature, blood pressure). Enteral feeding should be started cautiously with fresh mare’s milk or colostrum. Foals with severe gastrointestinal dysfunction should have enteral feeds withheld and should be started on parenteral nutrition. Since intestinal ischemia may predispose to ulceration, H2 blockers (cimetidine, ranitidine), proton pump inhibitors (omeprazole), or cytoprotective agents (sucralfate) are recommended.

D. Respiratory Dysfunction

Mild to moderate hypoxemia can be treated by increasing the amount of time the foal spends in sternal recumbency or standing and by administering modest flows of humidified intranasal oxygen (2–8 LPM). Foals suffering severe hypoxemia and hypercapnea (PaO2 < 40 mm Hg, PaCO2 > 65 mmHg) require positive pressure ventilation. Respiratory stimulants are used to treat periodic apnea and abnormally slow breathing patterns associated with central depression of the respiratory center. Caffeine is used most frequently to stimulate the respiratory neuronal activity and increase receptor responsiveness to elevated carbon dioxide concentrations. Overdosing with respiratory stimulants leads to excessive CNS, myocardial and gastrointestinal stimulation resulting in agitation, seizures, tachycardia, hypertension, colic, and diarrhea. Caffeine is the safest of the methylxanthines to use.

E. Endocrine Dysfunction

Ischemic adrenal gland injury can result in hemorrhage and necrosis and may result in decreased cortisol production. Hypocortisolemia might be suspected with inversion of the neutrophil: lymphocyte ratio without concurrent evidence of sepsis.

F. Immune Dysfunction

Maladjusted foals are at increased risk for failure of passive transfer (PPT) due to their abnormal nursing behavior. Serum IgG levels should be evaluated and colostrum and/or plasma administered to treat PPT.

G. Nutritional Support

If gut function is normal, the foal should receive a minimum of 10% of its body weight in milk daily and the feeds slowly increased to 15 to 25% body weight in milk daily. Young foals should receive small feeds every 2 hours. The mare should be hand milked every 2 to 3 hours to maintain her milk production and to obtain milk for the foal. If mare’s milk is not available, artificial mare’s milk replacer or goat’s milk can be used. If intestinal injury is evident, the foal should receive parenteral nutrition using a solution containing dextrose, amino acids, and lipids.

6. Detection and Prevention of Peripartum Asphyxia

Indications of fetal asphyxia in utero include persistent fetal bradycardia (FHR < 60 bpm), loss of fetal movement and fetal heart rate reactivity, reduction in fetal fluid volumes, and large, increasing areas of placental detachment. Indications of asphyxia at the time of parturition include meconium staining of the foal and a low APGAR score. The APGAR score is used in newborn infants to assess severity of postpartum depression and birth asphyxia. APGAR stands for appearance, pulse, grimace, activity, and respiration. Mucous membrane color is used to determine appearance. Pulse is self-explanatory and should be 60 bpm soon after delivery and increase above 100 bpm within the first hour. Reflexes represent grimace and are assessed by stimulating the inside of the nares and pinnae and using the thoracolumbar stimulus. The thoracolumbar stimulus is performed by briskly running the thumb and forefingers down either side of the foal's
spine. A healthy foal should raise its head, throw out its front legs, and attempt to rise. Attitude is translated into muscle tone and the ability to sit sternal. Respirations that are shallow should be above 30 breaths/min immediately after birth. Each parameter is assigned a score of 0 to 2 depending on response. The highest score of 10 is assigned to foals between 5 and 15 minutes of age with normal heart and respiratory rates, good muscle tone and reflex activity, and pink mucous membranes.

Umbilical cord samples can be used to assess fetal asphyxia, which can by definition implies hypercapnea, hypoxemia, and acidosis. Arterial blood gas values for healthy, term foals immediately post partum are as follows: PaO$_2$ = 43 mmHg, PaCO$_2$ = 53 ± 1.8 mmHg, pH = 7.323 ± 0.014. Increased newborn serum creatinine (>3.5 mg/dl) has been associated with placental dysfunction and PAS. Prepartum, the placenta functions as an in utero kidney and helps remove fetal creatinine. A low, presuckle glucose concentration (<35–40 mg/dl) in the newborn foal is associated with placental insufficiency and an increase of PAS.

A. Prognosis

With proper support, 70 to 75% of foals suffering from HIE and PAS recover. Most foals recover completely. Foals with the poorest prognosis develop sepsis, fail to show any signs of neurologic improvement within the first 5 days of life, remain comatose and difficult to arouse, and/or experience severe, recurrent seizures. Dysmature and prematurity foals suffering from prolonged in utero hypoxia are more likely to experience refractory hypotension and persistent subtle seizure activity than term foals. Rae, long-term CNS sequela includes unusual docility, vision impairment, residual spasticity, and recurrent seizures. Many of the “survivors” have gone on to perform successfully as racehorses and other athletes.

References

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