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Caring for Critically Ill Newborn Foals

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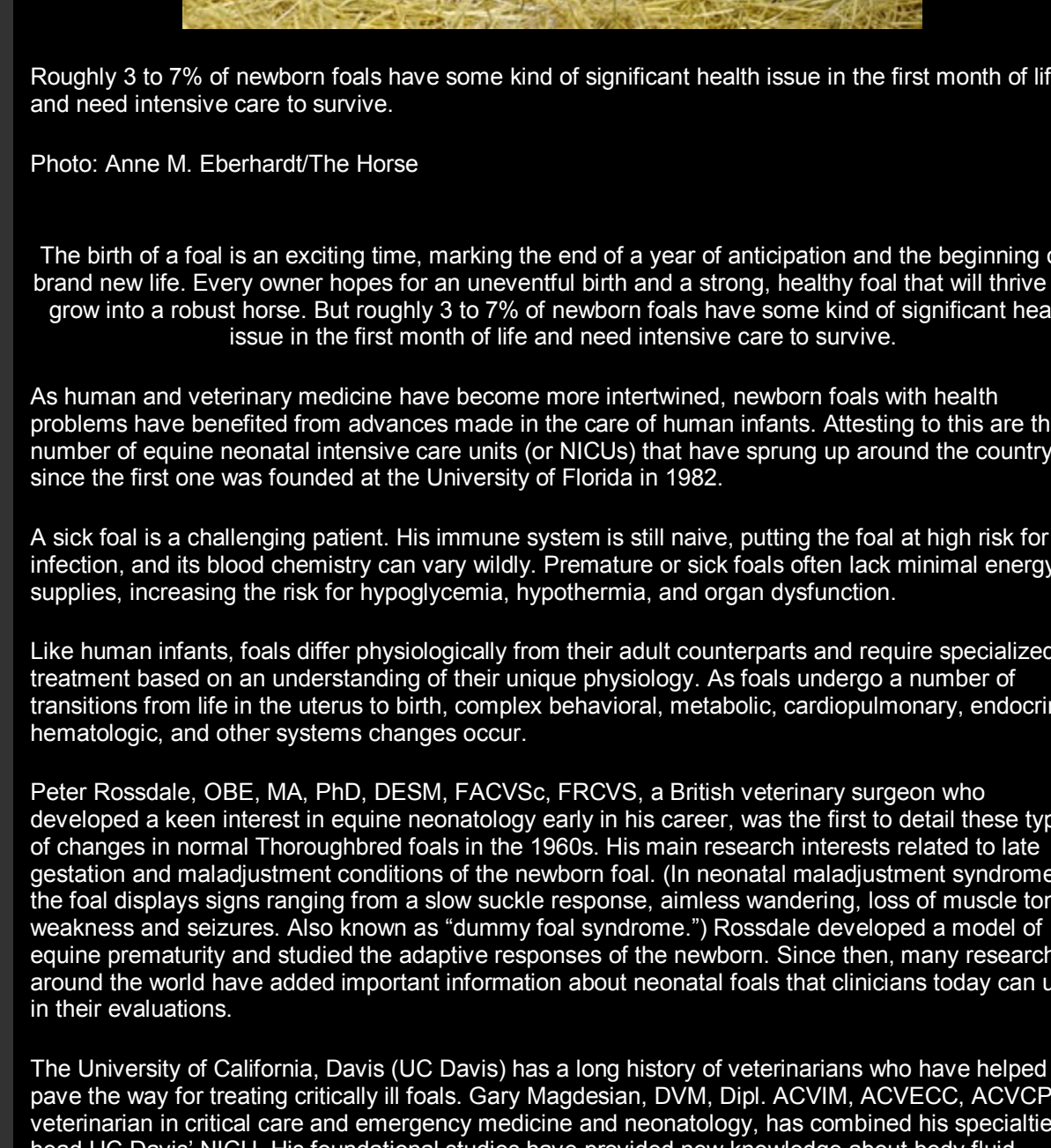


Photo: Anne M. Eberhard/The Horse

The birth of a foal is an exciting time, marking the end of a year of anticipation and the beginning of a brand new life. Every owner hopes for an uneventful birth and a strong, healthy foal that will thrive and grow into a robust horse. But roughly 3 to 7% of newborn foals have some kind of significant health issue in the first month of life and need intensive care to survive.

As human and veterinary medicine have become more intertwined, newborn foals with health problems have benefited from advances made in the care of human infants. Attesting to this are the number of equine neonatal intensive care units (or NICUs) that have sprung up around the country since the first one was founded at the University of Florida in 1982.

A sick foal is a challenging patient. His immune system is still naive, putting the foal at high risk for infection, and its blood chemistry can vary wildly. Premature or sick foals often lack minimal energy supplies, increasing the risk for hypoglycemia, hypothermia, and organ dysfunction.

Like human infants, foals differ physiologically from their adult counterparts and require specialized treatment based on an understanding of their unique physiology. As foals undergo a number of transitions from the uterus to birth, complex behavioral, metabolic, cardiopulmonary, endocrine, hematologic, and other systems changes occur.

Peter Rossdale, OBE, MA, PhD, DESM, FRCVSc, FRCVS, a British veterinary surgeon who developed a keen interest in equine neonatology early in his career, was the first to detail these types of changes in normal Thoroughbred foals in the 1960s. His main research interests related to late gestational maladjustment conditions of the newborn foal. (In neonatal maladjustment syndrome, the foal displays signs ranging from a slow suckle response, aimless wandering, loss of muscle tone, weakness and seizures. Also known as "dummy foal syndrome.") Rossdale developed a model of equine prematurity and studied the adaptive responses of the newborn. Since then, many researchers around the world have added important information about neonatal foals that clinicians today can use in their evaluations.

The University of California, Davis (UC Davis) has a long history of veterinarians who have helped pave the way for treating critically ill foals. Gary Magdesian, DVM, Dipl. ACVIM, ACVECC, ACVCP, a veterinarian in critical care and emergency medicine and neonatology, has combined his specialties to head UC Davis NICU. His foundational studies have provided new knowledge about body fluid content in foals, including their total protein and extracellular water concentrations, regulating blood glucose in foals, understanding the role of Clostridium difficile in foal diarrhea, establishing safe and effective dosage levels of antibiotics, and tracking congenital heart defects, to name a few.

Other veterinarians like Bill Thomas, DVM, Dipl. ACVIM, former chief of cardiology at the Veterinary Medical Teaching Hospital, and John Madigan, DVM, MS, Dipl. ACVIM, ACAW, a professor of equine medicine, examined cardiopulmonary changes in the foal at birth and in the neonatal period.

Monica Aleman, MVZ, PhD, Dipl. ACVIM, one of the few board-certified veterinary neurologists working in the clinical neonatal area, has performed studies on the normal ultrasonographic anatomy of the foal. She has also conducted studies on brain function in neonates, including brain wave studies in maladjusted foals, and electrophysiology research, which produced the first clinical method of diagnosing botulism in foals. Aleman recently documented that many sick foals suffering from conditions other than neonatal maladjustment syndrome have significantly elevated neurosteroid levels—a finding that could change the approach to field treatment of weak or disoriented foals.

David Wilson, BVMS, director of the Veterinary Medical Teaching Hospital, has contributed a great deal in the areas of pharmacology and to our knowledge of effective antibiotics in septic foals. Nicola Pusterla, DVM, PhD, Dipl. ACVIM, professor of equine medicine, has studied molecular markers of sepsis and the pharmacology of ceftriaxone, an antibiotic, in foals.



Dr. John Madigan inspects a maladjusted foal.
Photo: Joe Proudman/UC Davis

Madigan, whose decade-long study of neonatal maladjustment syndrome (dummy foal syndrome) resulted in a breakthrough that made headlines recently, was instrumental in establishing one of the early equine NICUs in the country. The NICU at UC Davis was established in 1987 and, like other pioneering NICUs around the country, acquired expertise by treating sick foals and working with neonatologists in human medicine. Boyd Goetzman, MD, PhD, then chief of the division of neonatology at the UC Davis Medical Center, was a mentor to Madigan, coming to rounds several times and consulting on individual cases. Together, Madigan and Goetzman ventilated the first foal ever, using surfactant commonly used for premature human infants. The foal survived.

A number of conditions can place a newborn foal in jeopardy:

- Sepsis (This state of both infection and a systemic inflammatory response is the major cause of death in foals less than 7 days old and is a common complication of other neonatal conditions such as prematurity or neonatal maladjustment. Different degrees of sepsis can include complications of organ dysfunction and circulatory failure.)
- Failure of passive transfer (transfer of antibodies from the mare to the foal via colostrum)
- Diarrhea
- Neonatal maladjustment syndrome;
- Hypoxic injury (oxygen deprivation in foals born from a difficult birth or with a congenital abnormality);
- Colic;
- Prematurity or dysmaturity (dysmaturity is the lack of development in a foal that has a normal gestation period);
- Respiratory distress/pneumonia; and
- Ruptured bladder.

When a weak or recumbent foal on a farm is evaluated by a veterinarian, it can be difficult to make a definitive diagnosis because many of the above conditions can cause weakness. Consequently, the approach might be to treat what is treatable and prevent what is preventable. In many cases, the goal will be to stabilize the foal before referral to a NICU where more intensive and continuous treatment can be provided.

"Sick foals decline rapidly, so aggressive early intervention is a key factor for survival."

Sick foals decline rapidly, so aggressive early intervention is a key factor for survival. Many foals have been treated successfully in field settings, but intensive care is warranted if the foal fails to stand or nurse within the first few hours. Lack of hair indicates a gestation period of less than 270 days. Note, however, that every mare has a different placental area and nutritional support, medications, milk feeding via nasogastric tube, and prevention of sepsis with antimicrobials. While this is a positive advancement, caring for a sick foal is labor-intensive, requires excellent collaboration between veterinarian and horse owner, and is stressful for the owner or caregiver.

For other sick foals—for example, foals that are premature/dysmature, septic, or in respiratory distress—referral to a NICU or hospital is necessary for survival. Again, the key is to get these fragile foals in quickly. In some cases, referral is not an option for financial or prognostic reasons. This is a personal decision to be made between the horse owner and veterinarian.

A Story of Hope for Amal
In the past, a premature foal (born less than 320 days of gestation) and normal gestation period is being to 360 days) was regarded as a lost cause with little chance of survival and even less hope of being an athletic adult. Today, prematurity is no longer a death sentence or an automatic label of nonathletic, thanks to equine NICUs around the country and accumulated wisdom.

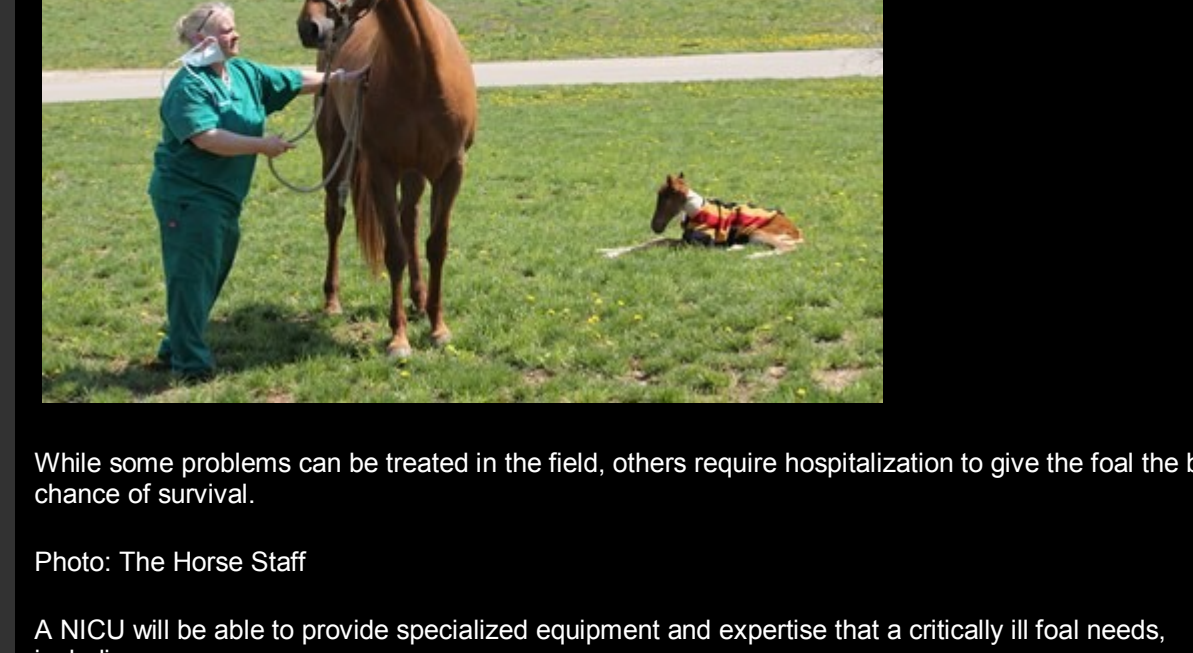
For Helen McCloskey, owner of a premature foal, neonatologists at UC Davis gave her foal the gift of life. The foal, named Amal, indicated a gestation period of less than 270 days and was born just 31 rounds from brought to the UC Davis Medical Center, was a mentor to Madigan, coming to rounds several times and consulting on individual cases. Together, Madigan and Goetzman ventilated the first foal ever, using surfactant commonly used for premature human infants. The foal survived.

"Amal's management was divided into short- and long-term approaches," Magdesian explained. "The short-term interventions included enteral nutrition through a feeding tube, antibiotics, enemas, a urinary catheter, IV (intravenous) fluids to stabilize her blood pressure, and oxygen insufflation into her lungs to help her breathe. The more difficult challenge was to ensure Amal's long-term survival."

Some of the long-term problems she presented were a lack of bone formation in her knees and hocks due to her prematurity, juvenile Arabian epilepsy, and a swallowing disorder (temporary pharyngeal paresis). Special care was required to prevent her from standing, which could cause permanent damage to her legs. As a result, she was mostly recumbent for one month. Many students and veterinary technicians provided round-the-clock care for Amal.

"I hope that Amal did move the science and art of neonatal care forward in some small way," McCloskey said. "I know she has touched many hearts and I received very kind words along the way, including a note from one veterinary student who said that as a result of her involvement in Amal's care, she had reconsidered her direction in veterinary medicine. That meant a lot."

"Amal is an athletic, enthusiastic smart youngster," she continued. "It was a great joy when she came home to me in September, though she still required a considerable amount of special care. She has challenges like a seizure disorder, which she has almost outgrown, but her future looks bright, thanks to the state-of-the-art equipment, care, and the many extraordinary students, staff, and veterinarians at UC Davis, particularly Amal's human godfather, Dr. Gary Magdesian."



A new foal should sit sternal with his head held up within moments of birth.
Photo: Anne M. Eberhard/The Horse

The Healthy Foal

One of the keys to identifying a problem in a newborn foal is to understand what a normal foal looks like. A new foal sits sternal (on his chest/belly) with head held up within moments of birth. He will shake his head, lick his lips, and will often start to vocalize when he sees and hears his mother. He is attached to the umbilical cord until the mother stands, at which point the cord breaks at an ideal distance from the body wall, with minimal bleeding. Most healthy foals will stand within one hour, nurse within two hours, and show great affinity for their mothers and a strong urge to suckle.

The foal will initially display jerky, uncoordinated movement that improves with each passing hour. The consumption of antibody-rich colostrum is vital to dosing and protecting the newborn gut, conferring normal immunity and providing the much needed nutrients and hydration (i.e., energy) for continued activity.

Consumption of milk is verified by audible swallowing and the baby will nurse briefly several times per hour, with periods of sleep between feedings. Most foals will urinate within hours of foaling (average of six hours for colts and 10 hours for fillies) and the onset of nursing will stimulate the first stool production, known as the passage of meconium, within an hour of birth. This initial manure is dark in color and turns a light tan once mare's milk has been digested and meconium has completely passed (often within 10% of foal body weight) and to ensure that it was passed completely. Normal expulsion occurs as the third stage of labor, and the placenta is considered retained three hours postpartum. Retention of the placenta for longer than three hours should be considered an emergency. The mare's mammary development will also be noted.

The veterinarian will then turn his or her attention to the foal. Mares can be very protective of foals, and an assiduous effort to better understand a gestation period of less than 270 days in cases of suspected respiratory rate or heart rate can be done before any foal handling if the foal is resting. This minimizes the effect of excitement on the vitals. The foal will often stand once the rectal temperature is taken and will require gentle restraint for the rest of the exam. Again, proper restraint of the mare during this exam is crucial and a team of veterinarian, mare handler and foal handler is ideal to safely and accurately accomplish the post-foaling exam.

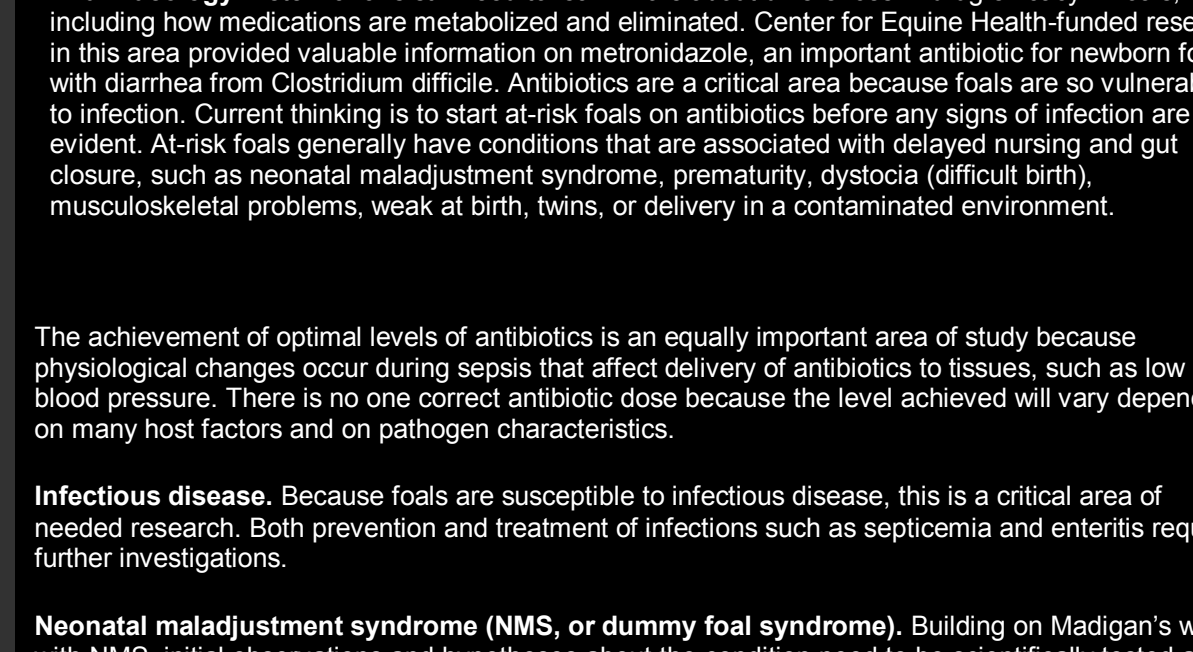
Reasons to Call the Veterinarian

Foals are very different from adult horses in their susceptibility to disease and in their resilience. The neonatal period is the riskiest time in the life of a horse. Hours can make the difference between life and death, so prompt action is crucial. Some foals might seem normal at birth and then start to display behavior that requires veterinary intervention. This is why it is important to carefully observe any new foal in the first few weeks of life.

"The neonatal period is the riskiest time in the life of a horse."

Call your veterinarian if you observe:

- Prematurity or dysmaturity. The normal gestation period for foals is 320 to 360 days. A foal is considered premature if its gestational age is less than 320 days. Note, however, that every mare has her own "normal" gestational length and that they tend to be fairly consistent from year to year. In other words, 320 days may be normal for one mare but very premature for another. Dysmaturity means immature development in spite of normal gestational age, so foals that are dysmature exhibit signs of prematurity after a normal gestation period. Signs can include:
 - Small size, floppy ears, domed forehead, flaccid lips, silky haircoat, and sometimes slipper-like hooves. Lack of hair indicates a gestation period of less than 270 days.
 - Abnormal placental location, where the fetus was restricted by the uterus or in cases of twins.
 - Incomplete ossification (lack of bone development) of the small cuboidal bones of the carpi (front knee) and hocks, and tendon/ligament laxity.
 - Abnormal white blood cell parameters identified on a complete blood count.
 - Dysphagia or temporary loss of coordination of swallowing muscles. This manifests as milk dripping from nostrils or mouth and puts the foal at risk for aspiration pneumonia.
 - Premature/dysmature foals require advanced support and referral if they are unable to stand or nurse.



A foal that spends excessive time laying down or asleep should be cause for concern.
Photo: Photos.com

Decreased activity and nursing. This is often the first sign of a problem. Depending increasing time laying down or asleep should raise concern. The mare's udder will be more pendulous than normal or even drip milk. This can progress to lack of suckle reflex or attachment to the mare.

Fever. Any change in behavior warrants obtaining a rectal temperature. An temperature over 102°F or under 99°F in a depressed foal requires immediate communication with your veterinarian. However, only about 50% of foals with infections have fevers, so lack of a fever does not rule out infection.

Seizures. Mild seizure activity in a foal can be as subtle as staring off into the distance with excessive blinking. Grand mal seizures often involve a loss of consciousness and large-scale tremoring in lateral recumbency. Causes can vary from infection to toxemia (acidemia) to hypoxemia (acidemia) to hypoxemia (acidemia). Common signs of infection include fever, depression, and loss of appetite. Common signs of hypoxemia include cyanosis (blue-tinged mucous membranes), rapid breathing, and loss of appetite. Common signs of toxemia include depression, loss of appetite, and loss of interest in nursing. Immediate veterinary intervention is warranted.

Diarrhea or colic in neonates is worrisome and immediate veterinary intervention is advised. Diarrhea puts the foal at risk for dehydration and can be caused by infectious agents, parasites, consumption of a large amount of milk, or ingestion of a large amount of milk. Vomiting, regurgitation, and fluid administration are often required and failure to respond warrants referral. Mild diarrhea one to two weeks of age in a foal with normal behavior and nursing activity, also known as foal heat diarrhea, is an exception to this rule. Note that "foal heat diarrhea" has nothing to do with the mare's first heat cycle but rather is due to maturation of the gut. Normal foal manure is semiformal and is not similar in appearance to adult horse manure.

Common causes of neonatal colic include meconium impaction, viral or bacterial infection (infection type varies with age of foal), overfeeding, ruptured bladder (abdominal pain), gastric ulceration, and parasitism.

Lameness or swollen joints require immediate examination. Never assume the mare and foal are OK on the hoof. Neonatal lameness is often associated with sepsis and spread of infection to the joint or growth plate, often in the first 30 days of life. Common signs of infection include fever, depression, loss of appetite, and occasionally penetrating wounds. Time is of the essence in these cases and prognosis declines rapidly if not treated in the first 24 hours of symptoms. Referral to a NICU is recommended.

Labored respiration in the foal is a cause for concern. Any sign that impairs oxygen delivery can cause an increased rate of effort. Pneumonia can occur with septicemia and can be seen in the foal. Foals often fail to cough or display abnormal lung sounds and often do not have any nasal discharge. Bacterial or viral infections will vary based on age of the foal. Laboratory work and imaging are necessary to diagnose pneumonia and much of this can be accomplished in the field. A respiratory rate less than 20 or greater than 60 can be a significant cause for concern, and these foals often require oxygen supplementation in the NICU if the rapid respiratory rate is associated with respiratory abnormalities.

Abnormal mucous membrane color (yellow or grey) can indicate an underlying problem and warrant immediate investigation. Some mares develop antibodies to the red blood cells of their foals and these foals develop a condition known as NI (neonatal isoenyolysis). The colostrum they consume contains antibodies which destroy their own red blood cells and causes icterus—a yellow discoloration of the mucous membranes. This condition often develops at three to five days of age and can be treated successfully in the field if identified early. It is also easily prevented by testing of the dam's blood during the last four weeks of pregnancy.

Milk dripping from the nostrils of a foal can indicate a neurologic issue or a functional abnormality of the pharynx. Foals with this issue are at risk for pneumonia, and further investigation is warranted. Straining to urinate or defecate is not normal in the foal.

Meconium impaction is the most common reason for straining or flapping of the tail. This occurs in the first day or two of life and is often successfully managed in the field with diagnostic imaging and enema and fluid administration.

Straining to urinate can be indicative of a ruptured bladder in the foal. Colts are more likely than fillies to be affected and these foals will often show progressive depression and a distended abdomen. Foals with ruptured bladders require referral to a NICU for medical and surgical management, but have a good prognosis if not septic.

Swollen, cloudy, or weeping eyes requires immediate veterinary attention. Common foal issues include corneal ulceration from shavings or stall trauma, entropion (folding of the lid into the cornea), or more seriously, uveitis. Uveitis in a newborn can indicate sepsis and carries a poor prognosis.

Swollen or moist umbilicus. The umbilicus is the second most likely route of entry for infectious agents in the foal, after the gut. Swelling or moisture warrant immediate investigation and can be indicative of infection or a patent urachus. The urachus is the umbilical remnant that carried fetal waste from the foal's bladder to the outer placental sac. This structure can become torn or infected and pose a risk to the foal. The umbilicus can be imaged ultrasonographically in the field and most umbilical infections respond well to aggressive antibiotic therapy. Some umbilical conditions require referral and surgical removal. Occasionally, foals can have significant internal umbilical infections with no external signs.

Factors that Warrant Immediate Referral to a NICU

Get your foal to a NICU immediately if he or she:

- Does not have a suckle reflex and does not have normal gut motility to digest milk placed in the stomach via nasogastric tube.
- Requires oxygen administration, and heart rate and respiratory rate are not stable.
- Is unable to stand unaided. This can be due to weakness or to abnormal limb development.
- Is notably premature or dysmature.
- Cannot maintain normal body temperature (indicative of compromised circulation or maladjustment).
- Is not responding to supportive therapy in the field and remains depressed and weak.
- Develops unresolved diarrhea or colic.

While some problems can be treated in the field, others require hospitalization to give the foal the best chance of survival.
Photo: The Horse Staff

A NICU will be able to provide specialized equipment and expertise that is critical to ill foal needs, including:

- A controlled environment with minimal pathogens and ideal temperature, often with accommodations for mare nearby.
- Continuous care and observation by trained personnel.
- Continuous and monitored intravenous fluid and medication administration.
- Parenteral (intravenous) nutrition administration for foals with a dysfunctional gut.
- Immediate access to laboratory measurements (such as blood work) which are used to direct supportive therapy. Such tests are often performed two to three times daily or more, depending on how critical the foal is.
- Access to advanced imaging such as ultrasound, radiology, and computed tomography.
- Support and physical therapy for recumbent foals.

Access to Surgical and Anesthesiology teams with neonatal experience. NICU Techniques Applied in a Field Setting

Lessons from the NICU have given veterinarians some tools that can be used in the field to treat mild problems. These include initial assessment tools, thermoregulation efforts, nasal oxygen therapy, IV fluid resuscitation, glucose administration to foals that aren't nursing, and prompt medical therapy for infection. If the foal fails to improve with initial supportive care in the field, then prompt referral to a NICU is essential for survival.

The most common cause of weakness and inability to rise is birth asphyxia, maladjustment, and sepsis. Your veterinarian will take blood samples for testing and might start appropriate antibiotic therapy based on research on susceptibility to common pathogens of neonatal foals. Because foals process medications differently from adult horses, dosages should be adjusted for the foal. If the foal fails to respond to initial treatment and is unable to rise or nurse on its own, referral to a NICU is warranted. Survival rates go down dramatically with delay in these cases, because:

Measurement of a foal's antibody level as indicated by blood IgG (immunoglobulin G) is a critical component to ascertaining health and risk for sepsis, particularly since a milk titer not show signs of infection in the early stages of sepsis. A stall side kit is available to analyze a small amount of blood taken from the jugular vein. The antibody level should be greater than 800 mg/dl in a healthy foal that has consumed enough good-quality colostrum by 12 to 18 hours of age. Foals with lower IgG levels should be managed carefully to minimize chances of infection. Failure of passive transfer or low IgG levels puts the foal at significant risk for infection and is time-sensitive. Remember: Even if a foal has an IgG of 800 mg/dl, if it is in a dirty environment, it is still considered at risk for sepsis. The degree of protection from colostrum and IgG depends on the balance of bacterial exposure factors and degree of immune response.

In addition to antibiotic therapy, weak foals often require IV fluid administration, usually with supplemental glucose for energy. New research suggests that carefully calculated fluid doses are very effective at treating mild initial dehydration. Foals who fail to respond to such support or who require continuous IV fluid therapy should be referred to a NICU.

Insufficient oxygenation (lack of oxygen to the heart, lungs, and circulatory system) is another problem in the field that can render a foal weak and affect their behavior and affinity for the mare. Low oxygen or hypoxia can occur during gestation if the placenta is functioning poorly, is infected, or is too small to support the developing fetus. A stall side kit is available to analyze a small amount of blood. If the delivery is prolonged by dystocia or abnormal fetal position, or if the placenta separates prematurely from the uterus, producing a red bag delivery (Normally, the placenta stays attached to the mare's uterus until the foal is delivered and can breathe on its own. When the placenta separates prematurely, the foal loses its placental blood supply and receives oxygen before it is able to breathe. A red bag delivery is an emergency, and stall kits are present who know how to deliver the foal rapidly because it is going through the birth canal with no oxygen.) Mildly affected foals can be managed in the field if they are able to get up and nurse and stay adequately hydrated, but they should be protected with antibiotics because they are at increased risk of developing sepsis. Otherwise, they should be referred to a NICU for more intensive care.

Hypoxia can occur after birth if the foal's cardiovascular system is impaired by infection or by heart/lung abnormalities. Foals struggling with oxygen issues will often fail their time for standing and nursing and warrant immediate intervention. It makes good sense to involve your veterinarian early on in any dystocia (difficult birth) or red bag delivery. Delivery of oxygen to a foal via a face mask is possible in a field setting, but prolonged oxygen therapy requires careful monitoring by the veterinarian. If the foal fails to respond appropriately, it should be referred immediately to a NICU.

Advances Made in Neonatal Critical Care

Over the last decade, there have been a number of advances in critical care medicine for foals. Veterinarians have increased the understanding of fluid physiology and balance, which allows them to fine-tune fluid therapy and monitor changes over time in response to treatment. The ability to adjust serum electrolyte and glucose levels, for example, allows veterinarians to immediately respond to foals in crisis. This has had a significant positive impact on the survival of sick foals.

Antibiotic treatment has also improved. Through pharmacology studies in foals, veterinarians and researchers have a better understanding of how foals metabolize and eliminate antibiotics, allowing them to administer more effective dosages in more appropriate dosages. Studies have provided new dose protocols for life-saving antibiotics such as ampicillin and ceftriaxone. In a study of the widely used antibiotic metronidazole in foals, researchers found that foals do not eliminate the compound like adult horses; therefore, they need lower doses or longer dosing intervals. Further, veterinarians now have newer drugs with different, safer mechanisms of action, allowing treatment of septic foals via continuous rate infusion, which keeps antibiotic levels safely high with good outcomes.

Practitioners are also better able to monitor cardiovascular status to understand how well blood vessels and the heart are functioning in foals. In addition to electrocardiograms (known as ECGs, a noninvasive way to measure electrical changes in the heart), monitoring equipment has been borrowed from human medicine to measure oxygen saturation, blood pressure, and end-tidal carbon dioxide. This capability allows veterinarians to monitor how nutrients and oxygen are being provided to tissues and the heart are functioning in foals. For example, allows veterinarians to immediately respond to foals that cannot function as well as veterinarians. They are able to provide fluids and medications that increase heart muscle contraction and blood vessel tone and thereby increase blood pressure to deliver more oxygen to tissues.

Veterinarians can now provide new modes of mechanical ventilation to foals that have respiratory failure and cannot breathe on their own. The mechanical ventilators are those used for human neonatal medicine and have very modern capabilities.

Because foals are a precocious species, they need to get up and move around. Researchers have learned better ways to manage angular limb problems, including valgus (knock-knee) and varus (bow-legged) deformities; flexural limb deformities, including contracture (over at the knee) and laxity (down at the knee). The CEH has recently funded a clinical trial that will allow researchers to better correlate neurosteroid levels and NMS and assess how these levels change in response to a squeeze, which mimics the natural birth process. Less time in the birth canal could inhibit a natural process.

There have been parallel applications in humans in the concept of "Kangaroo Care," in which premature human infants are held against the mother with skin-to-skin contact for several hours a day. The benefits of this kangaroo care have resulted in a precipitous drop in premature infant deaths and include the benefits of a stabilized heart rate, more regular breathing, improved oxygen saturation levels, and more.

Sepsis score. This risk-scoring scheme for neonatal infection needs further validation as it currently has 74% sensitivity in predicting bacteremia. Further research is needed to identify a rapid, field-side test that is sensitive enough to detect infection in foals that have minimal clinical signs, early in the disease process, and specific enough to differentiate between infection and inflammation.

Neonatal critical care. Finally, the area of neonatal critical care in general is in need of research to further improve our management of these very sick newborns.

There is a continuing need for more research to improve veterinarians' ability to treat critically ill foals.
Photo: Anne M. Eberhard/The Horse

Areas of Needed Research

There is a continuing need for more research to improve veterinarians' ability to treat critically ill foals, including in the following areas:

Pharmacology. Veterinarians still need to learn more about differences in drug efficacy in foals, including how medications are metabolized and eliminated. Center for Equine Health-funded research in this area provided valuable information on metronidazole, an important antibiotic for newborn foals with diarrhea from Clostridium difficile. Antibiotics are a critical area because foals are so vulnerable to infection. In trials leading to stall-side kits, researchers have discovered that antibiotic resistance are evident. At-risk foals generally have conditions that are associated with delayed nursing and gut closure, such as neonatal maladjustment syndrome, prematurity, dystocia (difficult birth), musculoskeletal problems, weak at birth, twins, or delivery in a contaminated environment.

The achievement of optimal levels of antibiotics is an equally important area of study because physiological changes occur during sepsis that affect delivery of antibiotics to tissues, such as low blood pressure. There is no one correct antibiotic dose because the level achieved will vary depending on many host factors and on pathogen characteristics.

Infectious disease. Because foals are susceptible to infectious disease, this is a critical area of needed research. Both prevention and treatment of infections such as septicemia and enteritis require further investigations.

Neonatal maladjustment syndrome (NMS, or dummy foal syndrome). Building on Madigan's work with NMS, initial observations and hypotheses about the condition need to be scientifically tested and validated. The CEH has recently funded a clinical trial that will allow researchers to better correlate neurosteroid levels and NMS and assess how these levels change in response to a squeeze, which mimics the natural birth process. Less time in the birth canal could inhibit a natural process.

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