How to Provide Nutritional Support of Sick Neonatal Foals

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Foals are born with limited stores of glycogen and fat, and even short periods of starvation can result in profound hypoglycemia, weakness, and hypothermia. Accordingly, nutritional support of the sick neonatal foal is critical for a successful outcome. The initial goal of nutritional support is to meet resting energy and nutrient requirements. Nutrition can be provided by the enteral route, the parenteral (IV) route, or a combination of the two. Enteral feeding of mare's milk through an indwelling nasogastric tube is the preferred mode of nutritional support, but it requires adequate gastrointestinal function. Mare milk replacers or partially skimmed (2% fat) cow milk supplemented with 20 g/l dextrose can be used when mare milk is unavailable. Foals intolerant of enteral feeding should receive parenteral feeding in the form of a dextrose-amino acid or dextrose-lipid-amino acid mixture. Authors' addresses: Marion Scott DuPont Equine Medical Center (McKenzie); and Middleburg Agricultural Research and Extension Center, Virginia Tech, VA (Geor); e-mail: hmckenzi@vt.edu. © 2007 AAEP.

1. Introduction

One of the challenges faced by any clinician when treating a sick foal is developing an appropriate nutritional plan to ensure that the foal has adequate energy and nutrients for basal metabolism, immune function, and growth. This seems to be a straightforward endeavor in which one simply calculates the number of calories required by the foal, determines the volume of the appropriate nutrient-containing solution, and provides this nutritional source by either the enteral or parenteral route. However, the energy requirements for sick foals are not well defined and likely to vary between patients. Also, the ability of the foal to appropriately digest and metabolize the nutrients provided is not guaranteed, because both age and degree of illness will impact gastrointestinal, endocrine, and metabolic function. Another difficulty arises from the fact that the energy content of a mare's milk is not consistent over time and is not the same as other mares’ milk. The exact formulation of substitutes such as artificial milk replacer is not always known. The burden falls on the clinician to not only formulate the best plan possible with the information at hand but also to ensure that the foal is closely monitored to ensure that the goals of the nutritional plan are met and that complications are avoided. By developing an understanding of normal foal nutrition and metabolism, one can approach the sick neonate with a sound basis for developing a nutritional plan and responding appropriately when the inevitable deviations occur.

2. Foal Metabolism

The Healthy Foal

The foal's nutritional requirements and dietary composition change substantially as the foal undergoes
the gradual transition from neonate to weanling. This means that careful consideration of the foal’s stage of growth is required when formulating a nutritional plan. At birth, the foal must transition from a continuous supply of nutrients provided by the dam through the placenta to intermittent absorption of ingested nutrients. At the same time, the metabolism of the neonate is no longer able to depend on the maternal glucose concentration to maintain normoglycemia, and the pancreas assumes responsibility for regulating glucose homeostasis. These dramatic alterations in energy metabolism may not always occur smoothly, and the foal possesses limited energy reserves in the form of glycogen and fat. The result is that hypoglycemia can occur in even the normal neonatal foal, and sick foals are at risk of profound hypoglycemia if deprived of energy intake for even a few hours.

The caloric requirements of young, healthy foals are sizable because of the need to support not only basal metabolic needs but also to maintain a rate of growth of as much as 2.5% of body weight per day during the neonatal period. In the neonatal period, the caloric requirement is as much as 150 kcal/kg body weight/day. It decreases to ~120 kcal/kg/day at 3 wk and then to 80–100 kcal/kg/day by 1–2 mo.1,2 Because these measures are given in terms of foal body weight, it is important to realize that the energy requirement per 1 kg is decreasing as the foal’s body weight is increasing. The result is an increase in the total caloric requirement with increased age. The initial energy source for the foal is mare’s milk, which has substantially greater lactose content than cow’s milk but lower milk-fat content. On a dry matter basis, mare’s milk averages ~64% sugar, 22% protein, and 13% fat compared with 38% sugar, 26% protein, and 30% fat in cow’s milk. Appropriate endogenous production of insulin by the pancreatic β cells is required for the foal to use the high dietary carbohydrate load.

Maturation of pancreatic β cell function occurs very late in gestation in the fetal foal, and it can be dependent on the normal rise in fetal circulating cortisol concentration that occurs in the final days of gestation.3 This pre-parturient rise in cortisol facilitates “readiness for birth,” which contributes to the maturation in endocrine, respiratory, and cardiovascular functions. After birth, there is adaptation of the endocrine response to ingested carbohydrates. In a recent study, healthy newborn pony foals showed impaired glucose clearance after the administration of exogenous glucose on the first day of life, which suggests a degree of insulin resistance.4 By day 10 after birth, these foals showed increased rates of glucose clearance, but this response remained lower than observed rates in normal adult equines. This maturation may be an appropriate response to changes in the composition of mare’s milk (colostrum contains little lactose) and the volume of milk ingested, which is less on the first day of life than on subsequent days.1,4 Starting as early as the second day of life, foals will begin to consume small amounts of hay, grass, and grain. In addition, they will ingest maternal feces, which likely provides the initial microbial flora required to support digestion of these feed-stuffs. It is unlikely that grain and roughage are well digested until at least several weeks of age, at which point the foal begins the gradual transition from a milk-based diet to a forage-based diet. The amount of milk produced by the mare peaks at ~2 mo of lactation and then begins a steady decline until weaning. Therefore, the foal must begin to rely on ingestion of solid feed for an increasing proportion of its nutritional requirements. By 3–4 mo of age, hindgut fermentation function is fully established. By the age of 6 mo, the foal is receiving <30% of total nutritional requirements in the form of milk, which allows for a fairly easy dietary transition when weaning occurs. As the foal’s hindgut function increases, there is a corollary shift in the primary energy substrate from carbohydrates absorbed in the small intestine to volatile fatty acids absorbed from the large intestine.

The Sick Foal

When evaluating the sick neonatal foal, one must always keep in mind the possibility that disease processes may have developed in utero. Maternal illness, malnutrition or toxin exposure, and placentitis or placental insufficiency all have the potential to profoundly influence the development and maturation of fetal metabolism. Studies investigating the role of a “restricted” uterine environment on fetal development have shown lifelong impairment of growth and development in affected foals.5 Conversely, the provision of a “luxurious” in utero environment can lead to enhanced growth rates to 3 yr of age.5 The influence of maternal diet is shown by a study where the provision of a diet high in soluble carbohydrates to the mare in late gestation contributed to a decrease in insulin sensitivity of the foals at 160 days of age.6 This study illustrates the potential for lifelong effects on metabolic function secondary to this “prenatal programming” effect, which potentially could be a contributing factor to the development of adult metabolic disease.7 This prenatal programming may affect the neonatal foal’s ability to appropriately metabolize nutrients in the clinical setting, and foals from a compromised placental environment may exhibit insulin resistance and carbohydrate intolerance.

As previously discussed, the late gestation rise in fetal cortisol is critical for final maturation of endocrine and metabolic function. Foals delivered prematurely may fail to undergo this rise in fetal cortisol concentration, and there may be resultant impairment to metabolic regulation after birth. Hypoglycemia, complicated by decreased endogenous energy reserves, and the impairment of nursing because of concurrent weakness, depression and/or difficulty standing are common problems in these foals. These foals can be intolerant of enter-
ally or parenterally administered carbohydrates because of impaired endogenous insulin production and/or insulin resistance, and they may develop profound hyperglycemia. Foals with systemic inflammation (e.g., sepsis) may also exhibit hyperglycemia because of insulin resistance. Management of these foals may require the use of lipid-containing parenteral nutrition solutions and/or the administration of exogenous insulin to achieve adequate caloric input.

Estimating the true caloric needs of the clinically ill foal is one of the greatest challenges in designing a nutritional strategy. Historically, it was believed that critical illness created a “hypermetabolic” state where the patient had increased energy needs because of increased tissue-energy consumption. Although data are scant, the energy requirements of the sick foal do not seem to be as high as once was thought. Indeed, overall metabolic rate may be markedly lower compared with healthy foals because of a decrease in activity level in combination with a temporary reduction in growth rate. Indirect calorimetry testing of clinically ill foals in one study revealed that the resting energy requirement was only ~45 kcal/kg/day, which is one-third of the energy requirement for growing, active, normal foals.

In managing the critically ill neonatal foal, it may be preferable to pursue a hypocaloric approach in which one endeavors to prevent the foal from entering a severely catabolic state while accepting that all of the nutritional needs of the patient may not be met. This approach addresses the fact that aggressive nutritional support can result in overfeeding, the risks of which may easily outweigh the possible benefits of providing nutritional support. Excessive carbohydrate administration will lead to increased generation of carbon dioxide and can worsen hypercapnia in foals with compromised respiratory function. Excessive carbohydrate delivery will also result in hyperglycemia, which is considered to be a pro-inflammatory stimulus and has been associated with worsening of outcome in human critical illness. Overfeeding of protein will result in increased protein catabolism and can result in the potentiation and/or development of azotemia. The excessive administration of lipids may result in hypertriglyceridemia. In contrast to the risks of overfeeding, there is little evidence in human patients that short-term (several days) hypocaloric nutritional support results in worsened outcomes compared with regimens designed to meet the patient’s metabolic needs. Recent evidence indicates that this approach, especially in regards to maintaining stringent control of blood glucose concentrations, is associated with decreased rates of complications and improved outcomes.

3. Enteral Nutrition

The first step in the development of a nutritional plan involves selection of the route of nutrient delivery. Provision of nutritional support by the enteral route is generally preferred for two reasons. First, this is the most natural and physiologically sound means of nutrient delivery. Second, the intestinal mucosa is partially dependent on the products of digestion for energy and nutrients. A thorough evaluation of gastrointestinal function is needed before institution of enteral nutritional support. This will include abdominal auscultation, checking for gastric reflux, and possibly, abdominal radiographs and ultrasonographic examination for evaluation of bowel dimensions and motility. Foals with evidence of gastrointestinal dysfunction such as gastric reflux, bowel distension, increased bowel-wall thickness, and ileus are unlikely to tolerate enteral feeding. A conservative approach to enteral feeding is also indicated for premature or immature foals in which there may be incomplete development of the gastrointestinal tract. Foals with perinatal asphyxia syndrome may be intolerant of enteral feeding as a result of intestinal ischemic injury.

4. Enteral Support and How to Provide It

Mare’s milk is the preferred substrate for enteral feeding. Mare's milk is highly digestible and obviously provides the correct balance of nutrients for normal growth and development. Commercial mare’s milk replacers can be used, but it should be recognized that these products are bovine in origin and have lower digestibility compared with mare’s milk. This increases the risk of intestinal dysfunction associated with enteral feeding. Semi-skimmed (2% fat) cow’s milk to which 20 g/l dextrose is added can be used if mare’s milk or mare’s milk replacer is unavailable.

Foals that are unable to nurse the mare may be fed through a bottle, bowl, or nasogastric feeding tube. Many sick, recumbent foals have a weak and/or uncoordinated suck reflex, and therefore, milk should be administered through a feeding tube. Use of a small-bore, indwelling tube and feeding of small volumes at frequent intervals (e.g., every 20 min) is preferred over repeated passage of a nasogastric tube at 1- to 2-h intervals. Large-bolus feedings may overwhelm digestive capacity, and repeated passage of a stomach tube is an unnecessary stress on the foal. Another advantage of the small-bore, indwelling tubes is that they do not interfere with the suckle response. Therefore, the tube may be left in place as the foal is transitioned to feeding from the mare. The feeding tube should be inserted with the foal in sternal recumbency, and correct placement within the esophagus should be confirmed by radiography or endoscopy. The tube may be fastened to the external nares by sutures. At each feeding, it is important to check that the tube is still in place and that there is no reflux. The foal should be in sternal recumbency or standing when it is fed. Milk should be administered by gravity flow followed by a small amount of clean water to flush the tube. The tube should be capped between feed-
ings to prevent aspiration of air. Feeding tubes should be replaced every 1–2 days to reduce risk of gastrointestinal-tract infection.

A suggested initial rate of milk delivery is 2–3 ml/kg body weight/h or 100–150 ml/h for a 50-kg foal. This will provide ~2.4–3.6 l of milk to a 50-kg foal during the first 24 h of enteral support. Dextrose-containing fluids can be administered IV to provide additional calories during the transition to an adequate level of enteral feeding (see below). The feeding rate can be gradually increased over the next 2–3 days (e.g., increase to 4–5 ml/kg/h on day 2 and then to 6–8 ml/kg/h on day 3), which represents a total daily intake of ~10–15% of body weight. Simultaneously, IV caloric support (dextrose) can be gradually withdrawn. This feeding level will likely meet the resting energy requirements of hospitalized foals. Depending on the rate of clinical improvement and the length of hospitalization, it may be possible to increase the volume of feeding to 20–22% body weight/day, which approximates the milk intake of healthy neonatal foals.

Clinical monitoring should include frequent assessments of gastrointestinal function, including gastric reflux, intestinal sounds, abdominal distension, and quantity and quality of feces. Gastric reflux, bloating, colic, diarrhea, or constipation can indicate intolerance to enteral feeding and the need for adjustments to the feeding program. This may involve a decrease in the volume or frequency of enteral feedings or a switch to parenteral nutritional support.

5. Parenteral Nutrition

There are a variety of situations in which a foal may be unable to receive enteral nutrition or is unable to tolerate the volume of enteral nutrition required to support basal metabolism and growth. These range from the critically ill neonate with gastrointestinal complications to the suckling foal with severe enterocolitis. In these circumstances, the provision of nutrition by IV infusion (parenteral nutrition) aids in ensuring that the patient receives appropriate caloric and nutritional support in a controlled manner and eliminates concerns regarding intestinal absorption. The limitations of parenteral nutritional support are primarily because of the expense of this therapy and the risk of secondary complications. These complications may include hyperglycemia, hypertriglyceridemia, thrombophlebitis, and an increased risk of bloodstream infections.

The primary goal of parenteral nutrition, as with any type of nutritional support, is to ensure that the patient is supplied with adequate calories to support minimum basal metabolism and ideally, to provide additional support to allow for ongoing growth. If sufficient nutritional support is not provided, affected foals may develop a negative energy balance; this can result in catabolism of amino acids for energy production. Failure to provide adequate nutritional support may also have a substantial negative influence on the immune response. Short-term parenteral supplementation (<24 h) does not require that the patient receive a balanced nutritional source consisting of carbohydrates, amino acids, and lipids; if parenteral nutrition is expected to be administered for a longer period, then a more complete formula should be used.

Short-Term Caloric Supplementation

Carbohydrate-containing solutions represent the simplest means of providing IV caloric support to foals. A solution containing 5% dextrose can be used, and there are several options available including 5% dextrose in water (D5W), Lactated Ringer’s Solution with 5% dextrose, 0.45% saline with 5% dextrose, and hypotonic maintenance electrolyte solutions containing 5% dextrose. Fluids containing dextrose should not be used for initial fluid resuscitation, because this will almost certainly result in the delivery of excessive amounts of dextrose to a foal with any degree of dehydration, which could lead to profound hyperglycemia. After initial fluid resuscitation, the solutions containing both electrolytes and dextrose may be used as the primary fluids for maintenance therapy in foals with minimal ongoing fluid losses. Dextrose 5% in water is not a good choice as a maintenance solution because of the absence of electrolytes, and it is primarily useful in providing free water to patients with hyperosmolar conditions. The caloric content of a 5% dextrose solution is 0.17 kcal/ml, and therefore, an infusion rate of 10 ml/kg/h would be required to deliver ~40 kcal/kg/day (0.17 kcal/kg/h × 24 h/day = 41 kcal/kg/day). This rate of infusion is more than two-fold higher than the maintenance rate for a neonatal foal (4–5 ml/kg/h). As an infusion rate of 5 ml/kg/h (20 kcal/kg/day) is typically the maximal limit for administering these solutions, a 5% dextrose solution is not suitable as a primary form of parenteral nutrition. In addition, care must always be taken when adjusting the infusion rates of 5% dextrose-containing solutions in response to changes in the patient’s fluid status to ensure that excessive amounts of dextrose are not infused, especially in premature or very sick foals that are likely to be poorly tolerant of dextrose infusions.

Alternatively, a 50% dextrose solution can be delivered without further dilution using an infusion pump as long as additional isotonic fluids are being administered concurrently to avoid endothelial injury because of the hypertonic nature of this solution. Use of 50% dextrose solution should be avoided if an infusion pump is not available, because it is very easy to inadvertently administer an excessive amount of dextrose, which could lead to hyperglycemia. The caloric content of 50% dextrose solution is 1.7 kcal/ml, and an infusion rate of 1 ml/kg/h of this solution will deliver ~40 kcal/kg/day (1.7 kcal/kg/h × 24 h/day = 41 kcal/kg/day). This low rate of infusion means that the primary fluid needs of the patient can be met with a dextrose-free
isotonic electrolyte-containing fluid, and the infusion rate can be altered in response to changes in patient fluid status without concerns related to the requirements of the nutritional plan.

At the end of the first 24 h of treatment, the fluid-therapy plan and nutritional plan should be revisited to determine if the patient can begin to rely on enteral fluid and nutritional intake or if continued parenteral therapy is required. Because dextrose-containing fluids are a very incomplete nutritional source, they should not be used as the primary nutritional source for >24 h. Continued parenteral nutritional support will require the formulation of a more complete solution that provides amino acids and possibly lipids.

Parenteral-Nutrition Formulation

One important aspect of providing parenteral nutrition to foals is the inclusion of a protein source. The natural metabolic response to injury and sepsis is to increase protein degradation in muscle tissue. This catabolic response can be reduced by supplying a source of nitrogen or by increasing energy intake. The recommended ratio for non-protein calories (NPC) to nitrogen is 100:200 NPC/g N.18,19 The inclusion of lipids in the parenteral-nutrition formulation allows for the provision of a larger number of calories per unit volume compared with solutions containing only dextrose. Another advantage of lipid emulsions is that they are isotonic, thereby moderating the hypertonicity of the parenteral nutrition formulation and potentially decreasing the risk of thrombophlebitis. Unfortunately, formulating parenteral-nutrition solutions with lipids increases the cost of the solution and may increase the risk of complications.20 Hyperlipidemia can occur in association with lipid administration to foals, but it does not seem to result in adverse effects.13,20 Lipid emulsions are prone to contamination and promote bacterial growth. Because of these risks, the IV lines through which lipid-containing solutions are administered should be changed daily, substantially increasing client costs. In a recent report, the use of lipid-containing parenteral-nutrition solutions allowed for the provision of 40–92 kcal/kg/day (mean = 63 kcal/kg/day) to foals as opposed to only 25–66 kcal/kg/day (mean = 41 kcal/kg/day) with a dextrose-based solution.13

There are two basic approaches to the formulation of parenteral nutrition to foals. The first involves the exact determination of the anticipated metabolic needs of the patient; a formulation is developed to meet all of these needs in a fairly precise manner using a mixture of dextrose, amino acids, and lipids. This approach is fairly complex and is best performed using a computerized spreadsheet to aid in performing the various calculations. The second approach is more practical and consists of using two basic parenteral-nutrition formulas. One of these solutions is intended for short-term use and consists only of 50% dextrose and 8.5% amino-acid solutions (Solution I). The second solution incorporates a lipid energy source and is preferred for long-term administration or for administration to foals that are poorly tolerant of infused dextrose (Solution II). Solution I is formulated using 2000 ml of 50% dextrose6 and 2000 ml of 8.5% amino acids,5 whereas Solution II is formulated with 1500 ml of 50% dextrose, 500 ml of 20% lipids,8 and 2000 ml of 8.5% amino acids.13 The caloric density of these solutions is 1.02 kcal/ml for Solution I and 1.08 kcal/ml for Solution II. The ratio of NPC to nitrogen is 125 NPC/g N for Solution I and 131 NPC/g N for Solution II.

Administration of Parenteral Nutrition

An electronic infusion pump should be used when administering parenteral-nutrition solutions; the rate must be tightly controlled, and adjustments to the infusion rate must be made easily and accurately. Excessive rates of infusion can easily induce profound hyperglycemia, which has been shown in other species to be associated with severe complications and increased risk of death.21 The solutions used for parenteral nutrition are all hypertonic and can cause injury to the vascular endothelium, which increases the risk of thrombophlebitis. For this reason, it is recommended that parenteral-nutrition solutions be administered through a 20-cm long polyurethane long-term catheterb placed in the jugular vein, because this provides a “central” line in most foals. The use of a multiple-lumen catheter allows for one lumen to be dedicated to infusion of the parenteral-nutrition solution, which minimizes the risks of contamination. Catheter management is extremely important when foals are receiving parenteral nutrition, and the catheter site and vein should be monitored at least twice daily for heat, swelling, or exudation. Increased resistance to fluid flow in the catheter may be an indication of thrombosis deeper within the vasculature and will often necessitate the placement of a catheter in an alternative site, such as the opposite jugular vein, a cephalic vein, or a lateral thoracic vein.

All components of parenteral-nutrition solutions must be mixed in a sterile manner before administration. The bag containing the final parenteral-nutrition composition should be covered with a brown plastic bag during administration to protect it from light, which can degrade the amino acids within the solution. The rate of infusion (in ml/h) is calculated based on the desired kcal/kg/day to be administered. A reasonable initial goal is 40–60 kcal/kg/day. Although this does not fully meet the theoretical energy requirements of the neonate, it can be difficult to achieve higher rates of energy administration without encountering hyperglycemia and/or hyperlipidemia. The initial infusion rate of parenteral-nutrition solutions should be 50% of the calculated final rate, and the rate should be gradually increased every 1–3 h after monitoring of the blood glucose concentration to ensure that hy-
perglycemia (blood glucose > 180 mg/dl) is not present. When parenteral nutrition is to be discontinued, it is recommended that the infusion rate be gradually reduced by decreasing the infusion rate in 25–50% increments every 4–6 h while gradually introducing enteral feeding. It is important that blood-glucose monitoring is continued during this weaning process to detect or prevent the development of hypoglycemia.

Monitoring the Foal Receiving Parenteral Nutrition

The foal must be frequently monitored, especially during the initial phase of parenteral-nutrition therapy. This monitoring should include a general physical examination with close attention paid to neurological status and respiratory function. Rectal temperature should also be closely monitored, because fever is a common early manifestation of systemic infection. Blood-glucose concentrations should be frequently monitored. Initially, they should be monitored on an hourly basis until the patient has stabilized with the appropriate rate of parenteral-nutrition infusion and then, every 3–6 h for the first day of therapy. The frequency of blood-glucose monitoring is very dependent on the stability of the patient. It may need to be more frequent in the very critically ill but may not need to be monitored beyond every 12 h in the stable patient. Monitoring of urine output and urine-glucose concentration may aid in the detection of hyperglycemia. Although the actual renal threshold for glucose is not well described in foals, glucosuria and diuresis can be seen when blood-glucose levels exceed 180 mg/dl in many cases. Additional clinico-pathologic monitoring should consist of daily complete blood counts and serum-chemistry profiles in the critical case, whereas these can be performed every 48–72 h in more stable patients. Urine output should be monitored continuously in combination with intermittent monitoring of urine-glucose concentration because of the risk of hyperglycemia-induced diuresis and glucosuria. Ideally, body weight should be assessed on a daily basis to ensure that the foal is at least maintaining body weight while on parenteral nutrition.

5. Insulin Therapy

The critically ill foal will often show a degree of insulin resistance, and this can make it very difficult to achieve even a conservative rate of administration of IV nutrition. This problem can only be addressed by the administration of exogenous insulin. The administration of insulin to the neonatal foal is not to be undertaken lightly, because this therapy places additional demands on both the clinician and nursing staff to ensure that profound hypoglycemia does not occur. Intermittent dosing of SC insulin may offer some advantages in terms of simplicity of administration and moderation of effects, but this route of administration does not allow for changes in dosage over the short term. The use of continuous rate infusion (CRI) for the administration of insulin allows for a fairly rapid onset of action while also providing a simple and timely means of adjustment of the dosage. Because of the gradual saturation of the cellular insulin receptors, the maximal effect of CRI insulin is not typically seen until roughly 90 min after initiation of the infusion. The response to alteration of the rate of infusion occurs over a similar time frame, so one should take care to avoid altering the rate of infusion of parenteral-nutrition solutions too soon after changing the rate of insulin infusion.

An initial insulin-infusion rate of 0.07 IU/kg/h is generally well tolerated and represents a reasonable starting point. In general, it is best to avoid simultaneous alterations in both the insulin-infusion rate and the parenteral-nutrition infusion rate, because this can lead to a “roller coaster ride” wherein the blood-glucose concentration is rising and falling wildly because of the delay in the body’s response to these changes. Blood-glucose monitoring should be performed at least hourly for the first 2–3 h after initiation of the insulin CRI, and if hyperglycemia (blood glucose > 180 mg/dl) is persistent beyond the first 2 h of insulin therapy, then the insulin-infusion rate may be increased by 50%. Hourly blood-glucose monitoring should continue for an additional 2–3 h. This procedure for increasing the insulin-infusion rate may be repeated if hyperglycemia persists.

Conversely, if hypoglycemia (blood glucose < 60 mg/dl) is noted, then a bolus of 0.25–0.5 ml/kg of 50% dextrose solution should be administered intravenously over 3–5 min. The blood-glucose level should then be reassessed every 30 min for at least 90 min to ensure that hypoglycemia does not recur. If hypoglycemia does recur, then a second bolus of dextrose is administered, and the insulin-infusion rate is decreased by 50%. Close monitoring will then be required for another 60–90 min to ensure that hypoglycemia does not recur and that hyperglycemia does not develop.

Additional changes to the insulin-infusion rate are not usually necessary after a steady state has been achieved (i.e., the blood glucose level is stable and the desired rate of parenteral-nutrition administration has been achieved). Patient reassessment is indicated if one finds that the foal has become even more insulin resistant (requiring additional insulin administration to avoid hyperglycemia), because there may be an overall deterioration in the patient’s condition accompanied by increasing systemic inflammation.

References and Footnotes


Mila International, Florence, KY 41042.
Baxter Healthcare Corporation, Deerfield, IL 60015.
Normosol M with 5% dextrose, Hospira, Lake Forest, IL 60045.
Plasmalyte 56 with 5% dextrose, Baxter Healthcare Corporation.
Dextrose 50%, Baxter Healthcare Corporation.
Travasol 8.5%, Baxter Healthcare Corporation, Clintec Nutrition Division, Deerfield, IL 60015.
Intralipid 20%, Baxter Healthcare Corporation, Clintec Nutrition Division.