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NUTRITION OF THE DAM INFLUENCES GROWTH AND DEVELOPMENT OF THE FOAL

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Introduction

A 1996 Kentucky Equine Research (KER) study monitored the incidence of developmental orthopedic disease (Pagan and Jackson, 1996). The results of this study provided early evidence of the importance of nutrition of the mare to the proper growth and development of the foal. The farm in this study produced 271 foals. Ten percent of the foals showed signs of developmental orthopedic disease by radiography. The foals were weighed monthly from birth, and those weights were compared to a large data set of weights from other central Kentucky farms.

Foals with fetlock lesions tended to be small at 15 days, 3.2 kg below the average. Lesions were most often seen in foals born in January, February and March and were more prevalent in fillies than colts. Approximately 2% of the foals were affected and the average age of diagnosis was 102 days. Foals that developed lesions at a later age (379 days) tended to be normal-sized up to 120 days but grew faster than average and were heavier after weaning. Foals that developed hock osteochondritis dissecans (OCD) averaged 7 kg heavier than the Kentucky body weight (BW) average at 15 days. By 240 days of age these foals were 14 kg heavier than the population average. Average daily gains were significantly higher in the OCD group. Foals that developed stifle or shoulder lesions averaged 5.5 kg heavier than the Kentucky average at 25 days and 17 kg heavier at 120 days of age. Stifle and shoulder OCD lesions were diagnosed in approximately 2% of the foals at an average age of 336 days.

The mare has a tremendous effect on development of the foal through weaning. The size of the foal at birth is determined by genetics, nutrition, and uterine environment. Growth after birth is mostly a result of the mare's milk production. In utero growth of the foal is governed by actual placental size and competency and available area of healthy endometrium.

Fetal Nutrition

The placenta of the mare consists of fetal and maternal tissues in diffuse villous attachments. The villi are organized at around day 100-150 of gestation into complex tufts which cover the entire surface of the fetal membrane and fit into complex crypts of the endometrium. Health of the endometrium is important for the exocrine secretory glands that produce histotrophs that sustain the unimplanted embryo during the first 40 days of pregnancy. Inadequate "uterine milk" in early pregnancy or the development of an inadequate total area of functional microcotyledons on the surface of the allantochorion in later gestation will have deleterious effects on embryonic and/or fetal growth.

Allen (2006) listed three examples of nutritional restrictions and their effects on the equine fetus: (1) spontaneous embryonic death or resorption when twin conceptuses result in a reduction of fetal membrane absorption of "uterine milk;" (2) abortion of twin conceptuses around 7 to 9 months of gestation due to competition between fetal membranes and limited endometrial surfaces; and (3) age-related degenerative changes in the mare's endometrium, which result in the formation of fibrous tissue around groups of endometrial glands – called "gland nests" – that do not function, causing failure of lymph drainage and leading to development of lymph-filled endometrial cysts. The degeneration of the endometrium results in patchy areas where fewer and less well-developed microcotyledons results in a serious reduction in the level of nutrition available to the fetus.

Wilsher and Allen (2003) demonstrated that age and parity of Thoroughbred mares have a significant effect on the development of the microcotyledons on the placental surface. They reported a reduction in surface area of microcotyledons not only in older mares with age-related degenerative changes but also in young primigravid mares. The reduction in fetomaternal contact in the maiden mares resulted in lower birth weights compared to younger multiparous mares.

There appears to be a priming effect on the microcotyledon surface density after the first pregnancy. Placental weight was correlated with foal birth weight in a study of the effects of placental and fetal development in maiden Thoroughbred mares (Wilsher and Allen, 2003).

During the third trimester, mares become insulin resistant. This appears to be a mechanism designed to increase glucose uptake by the placenta. Williams et al. (2001) reported that during the third trimester approximately 40% of the insulin-stimulated glucose uptake was reduced. The crown-rump length of the equine fetus reaches its maximum length in mid-gestation. The growth in the last trimester is in body weight through development of muscle and increases in body fat.

Fetal development is dependent on maternal glucose supply. The increased transfer of oxygen and nutrients to support this high rate of metabolism is achieved by increased uterine blood flow, increases in weight and surface areas of the uteroplacental tissues, and a decrease in glucose consumption of uteroplacental tissue on a weight-specific basis.

Fetal energy metabolism is glucose-dependant and the maternal to fetal blood glucose concentration gradient is the most important factor for supplying energy. There is a direct relationship between glucose concentration and size and weight of the placenta, which correlates directly with foal weight (Allen et al., 2002).

Barron (1995) surveyed racetrack performance of Thoroughbred racehorses in the United Kingdom. Offspring from mares aged 7 to 11 years produced more successful offspring in terms of time-form-rating (an expression of racing merit) when compared to maiden mares or mares greater than 11 years of age. Finocchio (1986) reported that the third foal from a Thoroughbred mare was the most likely to be a stakes winner, followed closely by the fifth, second and fourth foals, respectively.

Cymbaluk and Laarveld weighed foals born to 13 primiparous and 19 multiparous draft-cross mares (1996). The mares were weighed and blood samples were drawn near delivery. Foals from primiparous mares were lighter with colts weighing an average of 169.2 kg and fillies an average of 145.2 kg while fillies and colts from multiparous mares were 177.8 and 173.3 kg, respectively.

Cymbaluk and Laarveld (1996) reported serum values of insulin-like growth factor (IGF-I) for foals born to primiparous and multiparous draft-cross mares. Foals born to multiparous mares had an average serum IGF-I of 386 ng/ml while foals born to primiparous mares averaged 237.5 ng/ml ($p < 0.065$). Colts (378 ng/ml) averaged higher ($p < 0.05$) serum IGF-I concentrations than fillies (254.5 ng/ml) regardless of dam parity. Colts also tended ($p < 0.12$) to be heavier than fillies (173.5 vs. 159.2 kg, respectively). Foals were weaned at 13 or 16 weeks of age, and in both cases growth rates and serum IGF-I concentrations were reduced. One to three weeks after weaning, growth rates returned to normal and IGF-I concentrations returned to preweaning values when weights rebounded.

Nutritional Status of Mares

When placental supply of nutrients is altered experimentally or by malnourishment, fetal growth and postnatal adaptive responses may be affected. Thoroughbred fetuses carried by pony mares after embryo transfer had low birth weight, took longer to stand and nurse, and had hypercortisolemia for 48 hours after foaling, indicating in utero stress. They also had precocious stimulation of the fetal hypothalamic-pituitary-adrenal axis (Ousey et al., 2004). In this study, pony foal embryos were transferred into Thoroughbred mares. These foals showed exaggerated pancreatic ß-cell responses possibly as a consequence of enhanced delivery of nutrients in utero (Forhead et al., 2004). These overgrown pony foals had higher basal insulin levels without insulin resistance, and glucose was removed from the blood at a faster rate than in the Thoroughbred-in-pony group.

Hay (1995) reported that acute maternal hyperglycemia produces an increase in uteroplacental glucose uptake with saturation kinetics that parallel those of the fetus. At mid-gestation there are developmental changes in placental glucose transport, and by the third trimester fetal growth demands more glucose.

Glucose diffuses down a concentration gradient from mare plasma to fetus. When the mare's diet is restricted for long periods and hypoglycemia becomes chronic, the fetus begins producing its own glucose. That in turn elevates the fetal glucose concentration relative to that of the mare and shifts the balance of glucose uptake by the uterus to placental metabolism and less to the fetus (Hay, 1995). The second adaptation to chronic hypoglycemia in late gestation is a reduction in placental weight.

The reduction in placental weight does not appear to include a reduction in surface area or glucose transporter numbers or affinity (Aldoretta et al., 1994). The changes associated with reduced glucose supply result in reduced fetal and placental growth; however, rates of metabolism are maintained to insure normal fetal and placental tissue while reducing drain on maternal metabolism (Hay, 1995).

Milk Production

The nutrition of the mare affects growth and development of the foal both in utero and via milk production. These effects carry over through 12 months or more. In a study reported by Cymbaluk and Laarveld (1996), 15 one-day-old foals fed milk replacer for 7 weeks were compared with 5 foals that nursed their dams. During the first 2 weeks, replacer-fed foals did not gain (0.46 kg/d) as rapidly ($p < 0.03$) as mare-nursed foals (1.73 kg/d). The resulting IGF-I values for replacer-fed foals (139 ng/ml) were lower ($p < 0.0001$) than values for mare-nursed foals (317.4 ng/ml). After the first 2 weeks, gains were similar between the two groups; however, serum IGF-I concentrations of replacer-fed foals were only 36% and 60% of values obtained for mare-nursed foals at 8 and 18 weeks of age, respectively. The differences between mare-nursed and replacer-fed foals in serum IGF-I concentrations persisted to 1 year of age, when the serum IGF-I concentration of mare-nursed foals (1,203 ng/ml) was 48% higher than that of replacer-fed foals (815 ng/ml).

In 2001, Williams and coworkers fed lactating mares a sugar and starch diet (59.4% NSC, 18.5% NDF, 3.2% fat) or a fat and fiber diet (34.1% NSC, 36% NDF, 16.6% fat). The researchers reported higher glucose and insulin area under the curves for the sugar and starch diets after a meal. Mares use glucose for milk production (Williams et al., 2001). Energy demands for lactation are among the highest for horses.

Mares can produce 11.8 kg of milk per day or 2.3% of their body weight during the first 30 days of lactation (Gibbs et al., 1982). Pool-Anderson and coworkers (1994) determined milk yield in Quarter Horse mares for early lactation (2-29 days) and late lactation (60-120 days). Daily milk production was greater ($p < 0.05$) during early lactation compared to mid-lactation (12.1 vs 10.8 kg, respectively) and tended to be greater ($p = 0.08$) during mid-lactation (11.7 vs 10.4 kg, respectively) in multiparous mares compared to primiparous mares but was similar between groups in late lactation.

The extreme demands for glucose during early lactation may represent a time when feeds with higher glycemic responses would benefit the mare and foal. Foals can begin digesting grain within 10 days to 2 weeks of birth. It will be 6 to 8 weeks before a functional hindgut will be able to contribute to the overall nutrition of the foal with forage. Declines in milk production and nutrient concentrations after 2 months may represent a time when foals should be given supplemental feed (Gibbs, 1982).

Hoffman et al. (1998) reported on the effects of dietary carbohydrates and fat influence on milk composition and fatty acid profile of mare's milk. The sugar and starch diet (SS) was high in corn and molasses (62.4% NSC) while the fat and fiber diet

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(FF) was high in corn oil, beet pulp, soy hulls, and oat straw (26.5% NSC). The findings revealed a 4.2-fold increase ($p = 0.028$) in IgG concentration from the colostrum of mares fed the FF diet versus the mares fed the SS diet 6 to 12 hours post foaling (3140 mg/dl vs 755 mg/dl IgG, respectively). The fatty acid profile was higher in linoleic omega-6 and trans-vaccenic fatty acids in the milk of mares fed the FF diet.

In 1999, Hoffman et al. supplemented a grain mix containing 80 IU/kg daily intake vitamin E with an additional 160 IU/kg of vitamin E (1999b). Mares were supplemented for 4 weeks. Within 2 weeks of foaling, serum IgG concentrations were greater ($p = 0.064$) and serum IgA tended to be greater ($p = 0.13$) in vitamin E supplemented mares. Presuckled colostrum of vitamin E supplemented mares was higher in IgG ($p = 0.005$) and tended to be in IgM and IgA ($p = 0.12$ and 0.12, respectively). Serum concentrations of IgG, IgM, and IgA of the foals reflected those of their dams' colostrum post-suckling.

The researchers suggested that the 4.2-fold increase in IgG in the colostrum collected 6 to 12 hours post foaling in the previous study was due to the vitamin E content of the corn oil (327 IU/kg). Corn oil is high in omega-6 fatty acids (linoleic acid). Hoffman et al. (1998) suggested that higher linoleic acid content of the milk would protect against gastric ulcers.

Kruglik et al. (2005) studied the effects of supplementation of 454 g of a marine-derived, protected omega-3 fatty acid source (PFA). The PFA supplement provided approximately 10.4 g of docosahexaenoic acid (DHA) and 8.6 g eicosapentaenoic acid (EPA) per mare daily. The control diet was top-dressed with corn oil. They reported mares fed PFA had elevated DHA ($p < 0.05$) for the first 3 weeks of supplementation, during foaling and 24 hours, 7 days, 14 days, and 21 days postpartum. EPA was greater for the PFA-supplemented mares at weeks 1 and 2 ($p < 0.05$) and at all times postpartum ($p < 0.001$). In milk, both DHA and EPA were higher ($p < 0.001$) in PFA-supplemented mares at all times. EPA and DHA were higher ($p < 0.001$) in PFA foals at all times.

Growth Regulators

Growth responds to energy availability. Energy for growth must be supplied in excess of maintenance requirements. Blood levels of glucose and insulin are key signals to the somatotropic axis. The most important hormones in the somatotropic axis are growth hormone (GH) and insulin-like growth factor 1 (IGF-I).

Growth hormone is necessary for normal postnatal bone growth and stimulates longitudinal bone growth in a dose-dependent manner (Cheek and Hill, 1974). The metabolic effects of GH include protein anabolism and enhanced utilization of fat by stimulating adipocytes to break down triglycerides and by suppressing their abilities to take up circulating fats. GH controls blood glucose by an anti-insulin effect suppressing the ability of insulin to stimulate the uptake of glucose into tissues and it enhances glucose synthesis in the liver. A major role of GH is to stimulate the liver and other tissues to secrete IGF-I.

IGF-I stimulates whole body protein synthesis rates. GH and IGF-I increase lean body mass and decrease adipocytes. IGF-I has insulin-lowering effects that improve insulin sensitivity. IGF-I stimulates the proliferation of chondrocytes. GH stimulates the differentiation of chondrocytes while IGF-I also stimulates differentiation and proliferation of myoblasts. Somatostatin is another hormone in the somatotropic axis that inhibits GH in response to low blood glucose. GH secretion is also controlled by a negative feedback loop with IGF-I (Figure 1). High blood levels of IGF-I lead to decreased secretion of GH not only by directly suppressing the somatotroph but by stimulating release of somatostatin from the hypothalamus. Integration of all factors leads to a pulsatile secretion of GH (Martin et al., 1989).

Feeding a highly hydrolyzable carbohydrate meal to growing horses may create exaggerated glucose and insulin responses. As glucose increases in the blood, insulin increases and lowers blood glucose. Low blood glucose stimulates GH, which in turn stimulates IGF-I. If IGF-I is too high then GH is suppressed. If GH and IGF-I reach abnormal levels, overproliferation of cartilage may contribute to OCD (Staniar et al., 2002). Glade and Luba (1987) found changes in T3 and T4 were affected in horses fed high-carbohydrate meals by gastric infusion and suggested these active growth regulators may be involved with the development of DOD.

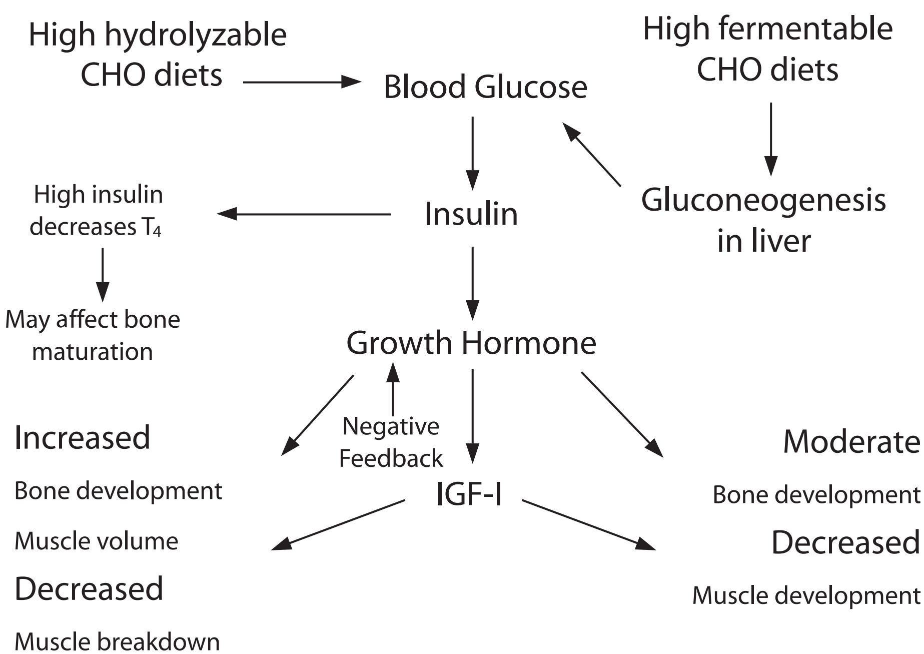

Figure 1. Growing horses fed highly soluble carbohydrate diets versus highly fermentable carbohydrate diets that provide the same DE may experience different growth patterns.

Ropp et al. (2003) fed a diet with 2.21% fat and 33.9% starch (CARB) and a diet with 10.3% fat and 24% starch (FAT) to weanlings for 60 days. On days 0, 30 and 60, blood samples were taken and analyzed for glucose, insulin, GH, IGF-I, and nonesterified

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fatty acids (NEFA). Over the 60-day period, the average daily gain (kg/d) was 0.85 for the CARB diet and 0.84 for the FAT diet.

On day 30 weanlings on the CARB diet had higher blood glucose concentrations and shorter duration in elevation postprandially. This was attributed to dietary fat sparing glucose and slowing down of gastric emptying. On day 60 there were no differences in blood glucose between treatments. There were no differences in serum insulin at 30 days, but at 60 days serum insulin was higher in the CARB group. Fat may have slowed gastric emptying and with adaptation the CARB group controlled blood glucose via higher insulin secretion. There was no consistent change in GH between diets. There was also no treatment effect on IGF-I. The authors concluded that neither the CARB diet nor the FAT diet had an effect on GH or IGF-I.

Savage et al. (1993) reported a higher incidence of dyschondroplasia in weanling foals fed 129% of NRC energy requirements to weanling foals for 16-18 weeks. The control feed was a rice-based pellet while the high-energy feed was the rice-based diet with 5% added corn oil. Hoffman et al. (1999a) developed a sugar and starch (SS) diet and a fat and fiber (FF) diet and fed them to mares and foals. The weanlings and yearlings were continued on the supplements for 16 months. The SS diet was partially composed of 61% corn and 10% molasses, a NSC content of 62.4%, a fat content of 2.4% and a DE of 3.00 Mcal/kg. The FF diet was oat-straw and beet-pulp based with 10.4% fat and 26.5% NSC and a DE of 2.98 Mcal/kg. All other nutrients met or exceeded NRC requirements.

Standardized subjective scores for evidence of developmental orthopedic disease (DOD), season and associated pasture growth, and hard ground during drought and freezing temperatures were more highly correlated with DOD than diet. In weanlings and yearlings fed the FF diet the bone mineral content (BMC) was lower from September to May between 140±5 days to 376±5 days of age.

Treiber et al. (2004, 2005) fed SS diets to Thoroughbreds raised on pasture that contained 49% NSC, 21% NDF, and 3% fat or FF diets with 12% NSC, 44% NDF, and 10% fat. As weanlings, the foals were tested by modified frequency intravenous glucose tolerance test. All samples were also analyzed for IGF-I. Insulin sensitivity was also estimated. Insulin sensitivity was 37% less in weanlings fed SS than those fed FF. The authors also tested acute response to glucose and developed a disposition index. They reported that decreased insulin sensitivity was compensated for by acute insulin response to glucose; therefore, there were greater insulin concentrations in the SS group. IGF-I was greater ($p = 0.001$) in SS weanlings.

Based on these studies, when fed at NRC nutrient requirements or above, there appears to be a range of interactive NSC, NDF, and fat that may alter glucose/insulin dynamics and affect GH and IGF-I in growing horses (Table 1). These ranges of NSC, NDF, and fat cannot be separated from energy balance. Staniar (2002) reported the greatest difference between IGF-I in diets similar to Treiber's SS or FF were greater during periods of rapid growth. He further reported that high correlations existed between ADG and temperature, suggesting pasture availability had a significant impact on ADG. ADG was also positively correlated with IGF-I.

Table 1. Lower glycemic diets for growing horses.

NSC, %	*NDF, %*	*Fat, %*
26-35	28-44	5-10

Further evidence of environmental effects was reported by Cymbaluk and Christison (1989) in which weanlings gaining 0.83 to 0.89 kg/d had maintenance DE requirements that were 27% and 57% higher than those reported for growing horses (Cymbaluk et al., 1989) and mature horses (Pagan and Hintz, 1986), respectively. While evidence exists that diets with high glycemic indices may be associated with DOD (Ralston, 1996; Pagan et al., 2001), there is no real evidence to support the claim that a low-glycemic diet will prevent this disease (Kronfeld et al., 2005).

Managers making decisions about feeding practices for growing horses must carefully consider pasture and forage quality, feeding frequency, environmental factors, genetic predisposition, and exercise before a complex decision is made concerning the glycemic properties of a supplemental grain source.

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