Transition Minerals and Vitamins: Impacts on Cow and Calf Health

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Introduction

Significant economic losses occur in agricultural enterprises as a result of prenatal and natal deaths and neonatal disease processes. Diagnosis of abortion losses still remains below 45% and a significant portion of these "idiopathic" abortions or stillbirths have been hypothesized to be related to nutritional causes. In a path model of risk factors for natal and prenatal deaths in beef herds, nutritional deficiencies and toxins were linked with every primary factor identified in causing these deaths as well as factors leading to inadequate passive transfer and neonatal disease.[1] Hepatic trace mineral concentrations were significantly lower in aborted fetuses compared to "control" slaughterhouse fetal specimens.[2] However, it has not been determined as to whether this finding suggests a direct role of trace mineral deficiency in abortion or whether it is a consequence of the abortion. Many specific trace mineral deficiencies can result in abortion, stillbirths or weak neonates.[3]

Assessing trace mineral and vitamin status of the fetus or neonate may provide critical information as to the underlying cause of a given diagnostic dilemma. Nutrient concentration within fetal or neonatal liver specimens or blood can be just as easily determined as is routinely completed for adults. Of concern however, is how one can interpret these concentrations relative to mineral or vitamin status. Can we assume metabolism is the same between fetal, neonatal and adult animals? Is it appropriate to use current criteria for adult animals on fetal and neonatal samples? If the answer to these questions are "no", then we may be mis-diagnosing many perinatal nutritional problems. In this presentation, maternal, fetal and neonatal mineral and vitamin nutrition concepts will be compared and contrasted to gain some understanding of the underlying physiologic processes. Role of these essential nutrients relative to fetal and neonatal health and survival will be discussed with recommendations for assessment and supplementation.

Vitamin and Mineral Metabolic Dynamics

Trace minerals are indirectly or directly associated with a tremendous variety of metabolic processes in animals of all ages. Deficiency diseases affect almost every physiologic and metabolic function and include immune dysfunction (Cu, Zn, Se); developmental abnormalities (Cu, Mn, I); abortion (Cu, I, Se); retained placenta (Cu, Se, I); metabolic disturbances (Co, Fe, Zn, I); and poor growth (Co, Cu, Fe, I, Se, Zn).[3,4] In addition and more importantly, subclinical disease resulting in reduced productive efficiency (reproduction, growth, lactation) and increased disease susceptibility is a more economically important problem associated with marginal mineral deficiencies. Subclinical disease is often difficult for the producer to identify within the herd without appropriate records evaluation and production bench marking. Presence of trace mineral deficiencies, clinical or subclinical, seem prevalent within the beef and dairy industries. Fat-soluble vitamins (ie, A, D and E) are associated with specific clinical disease manifestations, but much less is known relative to subclinical disease concerns.

Trace minerals and fat-soluble vitamins are not homeostatically regulated, but more controlled through movement between pools. Microminerals can be found in the body as a component to one or more metalloenzymes (biochemical function pool), transported on carrier proteins (transport mineral pool) or stored as a metal complex (storage mineral pool). Fat soluble vitamins are managed in a similar way, though they exert their biological effects as hormones affecting gene expression (A, D) or direct action (A, E). The body makes every effort to maintain a necessary level of activity in the biochemical pool to ensure normal function. The storage pool holds a reserve and is sensitive to nutritional status. If nutrient intake is in excess of requirements, excess intake will be stored until other regulatory processes, reduced absorptive efficiency or increased renal excretion, modify net mineral retention back into balance. Transport pool is dynamic in reflecting changes relative to either deficient or sufficient nutrient state. In a situation of nutritional inadequacy, hepatic storage will be mobilized and used to

maintain biochemical pool activity until absorptive efficiency, reduced excretion or both can be enacted to raise net retention.

Using these concepts of mineral pools within the body, Suttle has described four progressive phases of mineral deficiency disease.[3,5] Phases of mineral status move from depletion, loss of mineral in storage; deficiency, loss of mineral in transport pool; dysfunction, compromise of the function pool and finally disease (clinical signs associated with critically reduced function of a specific metalloenzyme). For example, copper deficiency reduces tyrosinase activity, which then decreases production of melanin pigment resulting in clinical signs of achromotrichia. Subclinical disease occurs during deficiency and dysfunction phases, often defined as impaired immune function, reduced growth rate or reproductive efficiency or other non-specific declines in productive efficiency. Disease due to deficiency of fat soluble vitamins would follow this same pattern of change in respective biologic pools.

Maternal-Fetal-Neonatal Interrelationships

The developing fetus is totally dependent upon availability of essential nutrients from placental transfer from maternal blood. As a result, fetal nutrient status is reflective of maternal nutrient status. Maternal nutrients available to the fetus would include those from the consumed diet as well as mobilized reserves, if needed. Swenson showed a decline in maternal liver copper concentration during late pregnancy, which would be consistent with maternal transfer of mineral to fetus.[6] A decline in maternal mineral status with progressing gestation was observed in beef cattle, but not dairy cattle, suggesting differences in supplementation relative to requirements.[7] Numerous studies have observed a fetal liver concentrating ability for minerals in finding fetal hepatic mineral concentrations to be nearly twice maternal values on a dry weight basis.[2,7-10]

In contrast to hepatic mineral concentrations, mean maternal serum selenium concentration was twice that of her fetus.[10] However, whole blood and erythrocyte selenium concentrations were not different between fetus and dam. Mean whole blood glutathione peroxidase activity was only slightly greater in the fetus compared to the dam. Whole blood and erythrocyte Se concentrations as well as whole blood glutathione peroxidase activity represent the functional pool of selenium as an antioxidant and these data suggest an approximately equal requirement for both fetus and dam. Observed differences between serum and liver selenium concentrations suggest altered transport and storage pools between dam and fetus. Higher maternal serum selenium concentration provides a substantial concentration gradient necessary for efficient placental selenium transport. Higher fetal liver Se concentrations infers a preferential storage of excess Se by the fetal liver over and above tissue requirements. Given these relationships, fetal liver and serum mineral concentrations must be interpreted differently from adult values.

Fat-soluble vitamins A, D and E do not appreciably cross the placenta as evidenced by much lower serum and liver fat-soluble vitamin concentrations in fetal samples compared to adult cattle.[11,12] Mechanisms for placental transport of fat-soluble vitamins exist, most likely to ensure sufficient amounts to meet fetal metabolic needs. The neonate's primary source of fat-soluble vitamins comes via colostrum ingestion supplied from an adequately supplemented dam. Maintenance of neonatal vitamin status will come from milk consumption.

During the early postnatal period, almost all essential nutrients are adequately provided for by milk consumption. However, a number of critical micronutrients, namely Cu, Fe, Zn and Se, are insufficiently to marginally provided by milk consumption alone, thus requiring additional sources to meet daily needs. Milk will contain some fat-soluble vitamins, but this will depend upon maternal supplementation. Fetal hepatic nutrient reserves play a critical role in maintaining adequate micromineral concentrations to support daily nutrient requirements in the milk-fed postnatal animal. Hepatic mineral reserves are augmented by consumption of colostrum, a highly concentrated source of most essential minerals and fat-soluble vitamins, which is dependent upon maternal nutrient status.

Role in Perinatal Disease

Clinical disease associated with specific trace minerals or fat-soluble vitamins has been described,[3] but these situations are not generally prevalent unless serious dietary issues are present. Marginal deficiencies of trace minerals have been clinically implicated in prenatal and postnatal disease issues leading to abortion, stillbirth, weak neonates and impaired immune response, but a definitive cause and effect has not been established through controlled studies.[1,3,4,13] The role of fat-soluble vitamins is less well defined. Survey studies have associated low hepatic copper, selenium, manganese and zinc concentrations with abortion with and without an identified infectious agent.[2,14] In a recent survey of stillborn beef and dairy calves, 67% of cases had low vitamin A and one or more trace mineral deficiencies (Van Saun, unpublished data, 2015). This observed role of vitamin A is consistent with other observations of low vitamin A status being associated with weak beef calves.[15]

Adequacy of neonatal nutrient reserves might explain differences in time frame and severity of specific nutrient deficiency disease occurrence. If a pregnant dam is severely deficient, mineral transfer to the fetus may be so limiting as to compromise normal functions, resulting in fetal death and abortion. If the deficiency is lessened but still serious, the fetus may die during parturition or soon thereafter. If mineral status is sufficient to maintain fetal development, hepatic reserves may be limited to various degrees. This then may result in clinical deficiency signs in the neonate within a week or two of birth. In other neonates where hepatic mineral reserves were slightly better, one might see clinical signs at one month or later or may not see clinical signs at all, but rather poor growth and performance. At this time, we do not know what mineral storage amount is necessary in the neonatal liver to minimize clinical and subclinical problems. Much more research in this area is needed.

Diagnostic Evaluation

A better database of adequate fetal and neonatal trace mineral and vitamin concentrations is required for proper diagnosis and monitoring. In attempting to determine mineral status, one needs to consider what question is being asked. First if one is interested in determining cause-effect relationship between a mineral deficiency and specific pathologic lesion, then one needs to look at the physiologic or biochemical role of mineral relative to biochemical function. On the other hand, what is most often asked is: What is the nutritional status of the animal? This is entirely different question and reflects the status of a different nutrient pool, the storage pool. Unfortunately collection of serum or whole blood is not the preferred specimen for determining nutritional status. Interpretation of this pool is difficult in many circumstances due to dynamic circumstances of nutrient flux through this pool. As a result of these relationships, collection of a liver biopsy specimen is the preferred sample to determine nutritional status of the animal. Liver samples can be obtained from any portion of the liver. No data has shown any evidence of mineral concentration variation within the liver.[16]

Given the described differences between fetal and maternal mineral metabolism, and understanding that neonatal mineral metabolism is a gradual progression from fetal to adult metabolic patterns, it seems obvious that adult-based diagnostic criteria cannot be used for either fetal or neonatal evaluations. Some diagnostic laboratories have recognized these differences and have established age-based criteria. At Michigan State University's Clinical Nutrition laboratory diagnostic criteria have been estimated for fetal, newborn (1-9 days), infant (10-29 days), juvenile (30-300 days), yearling (301-700 days) and adult (>700 days) age categories. This laboratory has a tremendously large database by which these criteria were empirically derived for vitamins A and E and selenium in serum and liver samples. Without age-based criteria, all younger animals and fetuses would be considered deficient in most trace minerals and vitamins. While this approach is a tremendous move forward in diagnostic capabilities, more data is needed to refine these diagnostic criteria. Our ability to make diagnostic interpretations from fetal and neonatal liver mineral concentrations may be improved if evaluations are based on age and hepatic dry matter content. More controlled research is needed to specifically determine adequate hepatic mineral concentrations in bovine fetus and neonate.

Supplementation Approaches

It is absolutely essential that the pregnant animal receive an adequate amount of all minerals and fat-soluble vitamins to support both maternal maintenance and conceptus development throughout the duration of gestation

to minimize deficiency disease problems of either the dam or neonate. House and Bell have suggested NRC mineral requirements were sufficient to support pregnancy,[17] but vitamins A and E were increased with the later NRC publication.[18] In beef cattle it is suggested to increase NRC mineral requirements during pregnancy by 125% to ensure sufficient fetal transfer and maintain maternal status. Dietary supplementation is more physiologic and should be maintained throughout the gestation feeding period. Challenges occur with the rumen in microbial degradation of fat-soluble vitamins (A predominately) and production of interfering agents. Often a recommendation to include between 25 and 30% mineral supplement from chelated or organic forms in made.

Injectable minerals and vitamins have been used to correct diagnosed deficiencies or in the place of dietary supplementation programs. Injectable minerals and vitamins are more biologically available, but increasing serum concentrations may result in a greater percent of the injected dose being excreted. Selenium deficient beef heifers administered a label dose of injectable sodium selenite excreted nearly 25% of the injected dose within 24 hours and selenium status adequacy was not achieved.[19] More recent work has shown some beneficial effects on cow performance with injectable minerals even when the diet fed was within recommendations.[20,21] A better understanding of how supplemental nutrition can influence immune response is necessary to better define mode and rate of trace mineral and vitamin supplementation to enhance cow and calf health and performance.

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