# SYMPOSIUM: PRACTICAL CONSIDERATIONS OF TRANSITION COW AND CALF MANAGEMENT

## Nutrient and Immunity Transfer from Cow to Calf Pre- and Postcalving

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### ABSTRACT

Nutritional and management strategies for dairy cattle are designed to prepare the cow for lactation and to minimize the incidence of metabolic diseases around calving. However, strategies initiated during the dry period should also consider the potential effects on the calf prior to and after calving. Fetal requirements for energy and protein are significant, particularly during the last trimester of gestation. Energy requirements increase to 1.3 to 1.5 times maintenance in late pregnancy; therefore, the formulation of rations for dry cows must contain sufficient energy to support fetal growth plus maintenance. Protein requirements during pregnancy increase, particularly during the last 2 mo. Colostrum is a source of immune components and nutrients to the neonate and contains more protein, immunoglobulins (Ig), nonprotein nitrogen, fat, ash, vitamins, and minerals than does milk. Because some vitamins do not cross the placental barrier, colostrum is the primary source of these nutrients for the calf after birth. Colostrum from cows that are not supplemented with vitamin E during the dry period may provide inadequate vitamin E to calves after birth. The Ig concentration in colostrum is not markedly affected by prepartum protein nutrition; diets containing high crude protein (CP) generally increase the nonprotein fraction of colostrum, but low CP diets do not affect the CP or Ig concentration of colostrum. However, data from beef calves suggest that absorption of IgG may be impaired when low protein diets are fed during the dry period. Diets for dry cows may be balanced to reduce the cation to anion ratio, which may reduce the incidence of parturient paresis. Recent research also suggests that these diets might increase the incidence of calves born in respiratory acidosis, which may impair the acquisition of passive immunity.
(**Key words**: calves, nutrients, immunity, calving)

**Abbreviation key**: AEA = apparent efficiency of absorption.

### INTRODUCTION

Management of dry cows has been referred to as management by benign neglect (11). In many commercial dairy operations, management of dry cows and bred heifers is minimal. Many producers incorrectly assume that the nutritional requirements are sufficiently low and that these animals can obtain adequate nutrition on pasture (often poor quality) or in a drylot with grass hay of fair to poor quality.

Research that has been conducted with dairy cows during the nonlactating period often has evaluated the effects of nutritional and managerial strategies for dry cows in preparation for lactation. Fewer data are available on the effects of nutrition and management of the dry cow on the health, growth, and survival of the calf during the periparturient period. Many of the strategies implemented during the dry period can affect the health and survival of the calf. The objective of this presentation is to review some of the research that has evaluated these effects.

#### Nutrition During the Dry Period

Typically, dry cows are placed onto pasture or drylots and are fed diets based on forages during the first 4 to 6 wk of the nonlactating period. Nutrient requirements are lower than during lactation (Table 1), and rations may be based primarily on forage. A goal of management during the early dry period is to evaluate the body condition of the animal and feed to attain a body condition score of 3.5 on a scale of 1 = thin to 5 = obese at calving (86). Unfortunately, some producers provide only poor quality grass forage or pasture for cows during the early dry period, thereby

TABLE 1. Nutrient requirements for dry, pregnant cows.[1]

| Item | NRC | Close up[2] |
|---|---|---|
| $NE_L$, Mcal/kg | 1.25 | 1.45–1.55 |
| Crude protein, % of DM | 12.0 | 13–14 |
| Neutral detergent fiber, % of DM | 35.0 | 40–55 |
| Ca, % of DM | 0.39 | 0.36–0.41 |
| P, % of DM | 0.24 | 0.22–0.25 |
| Mg, % of DM | 0.16 | 0.22–0.25 |
| K, % of DM | 0.65 | 0.70–0.80 |
| Na, % of DM | 0.10 | 0.12–0.15 |
| Cl, % of DM | 0.20 | 0.24–0.26 |
| S, % of DM | 0.16 | 0.19–0.21 |
| Fe, ppm | 50 | 60 |
| Co, ppm | 0.10 | 0.12 |
| Cu, ppm | 10 | 12–18 |
| Mn, ppm | 40 | 50 |
| Zn, ppm | 40 | 50 |
| I, ppm | 0.25 | 0.70 |
| Se, ppm | 0.30 | 0.30 |
| Vitamin A, IU/kg | 4000 | 4700 |
| Vitamin D, IU/kg | 1200 | 1400 |
| Vitamin E, IU/kg | 15 | 30 |

[1]Data are from NRC (88) and Van Saun (128).

[2]Close-up dry cows are in the last 2 to 4 wk prior to calving.

providing inadequate energy for maintenance and fetal growth. Other producers might attempt to increase body condition during the dry period by extended feeding of lactation rations or corn silage to prepare the cow for the forthcoming lactation.

Recent recommendations for dry cow management suggest that producers divide cattle into two groups based on the time before parturition (40, 55, 86, 128, 130). Rations are fed to meet nutrient requirements and to minimize postpartum metabolic disturbances, which commonly occur near calving and are often interrelated (26, 85). Rations formulated during the early dry period are usually simple; often forage, a small amount of concentrate, and a trace mineral salt constitute the dry cow ration. These diets are fed for 4 to 6 wk. Subsequently, cows are fed a close-up ration for the remainder of the dry period. This ration provides additional nutrients to support fetal growth, prepare the cow's digestive system for lactation, and compensate for the reduced DMI that occurs as cows approach parturition (128). Van Saun (128) estimated that DMI would be approximately 13.0 and 11.1 kg/d for a 650-kg dry cow during the early dry period and close-up period, respectively.

The growth of fetal tissues, particularly protein and energy, generally follows an exponential curve (12, 31, 52, 53, 88) between 6 and 9 mo of gestation. Consequently, energy and protein requirements increase significantly during the last 4 to 8 wk of gestation (53, 88, 98). Deposition of fat, protein, and glyco-gen account for most of the energy content of fetal tissues (12). Predicted metabolizable energy requirements during the last 8 wk of pregnancy are 40 Mcal/kg of $BW^{0.75}$ (12, 88) based on an efficiency of 14% of metabolizable energy utilization for conceptus growth (12). Requirements for protein accretion by the conceptus are less clear, primarily because of a lack of data related to the efficiency of use of metabolizable protein (11, 12). However, calculated CP requirements during late pregnancy are still ≤1.1 kg/d (12). When calculated in conjunction with maintenance requirements, the total CP requirement is still <12% of DM (88). Because of the uncertainty of several assumptions made in calculating CP requirements (11, 12), the recommendation of 12% of DM as CP seems prudent.

Data related to mineral accretion in the fetus and conceptus have been reported recently (52, 53). Generally, those data suggest that current NRC (88) recommendations for minerals (e.g., S, Se, Ca, P, Mg, K, Na, Fe, Zn, Cu, and Mn) are adequate for maintenance plus conceptus growth during the dry period.

Increased nutrient density of close-up rations provides the fetus with required nutrients during the final 2 to 4 wk of gestation. These rations are important and should be implemented whenever possible.

## Nutrient Imbalance During the Dry Period

Some data (32, 52, 98, 105, 106) suggest that prepartum nutrition does not markedly affect fetal size or chemical composition unless nutrition is markedly inadequate. However, nutrient deprivation before parturition may affect the survival of calves (20, 23, 24, 51, 132) and lambs (5, 6, 63). Conversely, excess nutrients (particularly energy) might negatively affect survival by increasing the incidence of overconditioning and periparturient disorders (85). Survival of lambs born from ewes fed diets to achieve BW gains of –1 kg/d during the nonlactating period was reduced compared with that of ewes fed diets to achieve +1 kg of BW gain/d (5, 6). Total body fat content and basal metabolic rate were also reduced. Corah et al. (24) indicated that nutrient restriction during the last 100 d of gestation resulted in lighter calves and lower survival near calving although calving difficulty was unaffected by diet. Many of these calves utilized amino acids for gluconeogenesis at the expense of protein synthesis (10).

Calves born from dams with inadequate protein intake before parturition might be more susceptible to morbidity and mortality. Inadequate protein intake

by dams before parturition may affect birth BW (13, 23, 67, 122). Carstens et al. (23) reported that heat production during feed deprivation was reduced by 11.4% for beef calves born from dams that were fed 55% of NRC (88) CP requirements from d 190 of gestation compared with that of dams fed 91% of the requirement. Nutrient deprivation of the dam may increase serum cortisol and reduce serum triiodothyronine (51). Consequently, calves may be born with reduced metabolic rates (23, 51), lower vigor, and, possibly, lower chances of survival.

Lactating cows may enter the dry period overconditioned because of delayed breeding, improper grouping strategies, poor milk production, or imbalanced ration formulation during lactation. Overconditioning as a result of excess energy intake does not appear to have a profound effect on fetal growth or development but does affect calf mortality and morbidity as a consequence of increased incidence of dystocia.

Dystocia is a multifaceted condition with numerous causative factors, including size and weight of the calf (97, 109), sex of calf (68, 97, 109), body condition (109), and others. Dystocia profoundly affects calf health and survival (76, 110, 136) and maternal lactational performance (75). Martinez (76) reported that calf mortality increased from 3 to 57% when calves were born with calving scores of 1 and 5, respectively (1 = normal delivery to 5 = severe dystocia). Calves that were born from cows with dystocia also have a higher rate of mortality and slower rates of BW gain (131). Vermorel et al. (131) reported that heat production of calves during the first 15 h after a difficult birth was markedly lower than that of calves delivered normally. Calves that experienced a difficult birth were also more likely to have lower blood pH, higher blood lactate, and lower NEFA concentrations (131). Thus, management to avoid overconditioning and the consequent risk of dystocia is important to calf health and survival. Proper nutrition during late lactation and the dry period of the dam, selection of proper bulls, and proper nutrition of heifers during the rearing period can reduce the incidence of dystocia.

Modification of the body condition score of cows during the dry period might also lead to increased risk of dystocia. Gearhart et al. (39) reported that cows losing the most body condition during the dry period were at greatest risk to develop dystocia at the subsequent calving. Those researchers (39) also suggested that feeding cows to lose body condition during the dry period might increase the risk of dystocia. Thus, overconditioned cows entering the nonlactating period and their calves may be at significant risk whether or not body condition is modified.

## Colostrum Quality

***Dietary effects on colostral Ig content.*** Effects of prepartum diet on colostral quality have been evaluated. Concentration of CP in the prepartum diet does not markedly affect the IgG concentration of colostrum (17, 22, 51). Hough et al. (51) fed Angus cattle 100 or 57% of NRC requirements for CP and energy from 90 d prepartum. Calves were fed 1 L of colostrum four times daily after birth from the dam or from a cow on the alternate treatment shortly after calving. The IgG concentration in colostrum or serum of calves at 24 h did not differ between levels of nutrient supplementation. However, when calves were fed colostrum that was obtained from cows that were fed restricted amounts of energy and CP, absorption of IgG was reduced by 21.8% compared with that of the control. Hough et al. (51) suggested that a constituent of colostrum affecting IgG absorption was altered by restriction of the maternal diet. Burton et al. (22) also reported that, although dietary CP restriction did not affect colostral Ig concentration, absorption of $IgG_1$, $IgG_2$, IgM, and IgA were reduced in calves born from dams that were fed restricted diets.

Other research suggests that dietary restriction may not affect the transfer of passive immunity to calves. Olson et al. (91, 94) and Halliday et al. (45) reported that restriction of maternal nutrition has little effect on the composition of colostral Ig or the ability of the calf to absorb Ig after its consumption. Fishwick and Clifford (35) reported no effect of a diet containing 10.9% CP during the last 14 wk of pregnancy on the composition of colostrum or on the amount of Ig absorbed by calves. Al-Sabbagh et al. (7) also reported that body condition score had little effect on colostral IgG concentration in ewes with body conditions scores of 2.5 to 3.5 (on a scale of 1 = thin to 5 = obese). Clearly, the relationship between the prepartum diet and the acquisition of passive immunity merits further investigation.

***Effects of ambient temperature.*** Heat stress can markedly affect colostral composition and Ig content. Nardone et al. (87) reported that colostrum yield was not reduced when Holstein heifers were exposed to high ambient temperature (31.5°C with 72% relative humidity from 0900 to 2000 h and then 26°C with 72% relative humidity from 2100 to 0800 h). However, total fat, lactose, energy, CP, IgG, and IgA were lower than those for heifers maintained in a thermoneutral environment.

***Volume of colostrum produced.*** The volume of colostrum produced might negatively affect colostral Ig concentration (99), although others have indicated no relationship between the volume of first-milking

colostrum and IgG concentration (103). The negative relationship between volume of colostrum and colostral IgG concentration might be related to the onset of lactation in cows around parturition. If lactogenesis begins before calving, milk might effectively dilute the IgG accumulating in the udder during colostrogenesis (43, 138).

*Other factors.* Other factors that can influence the quality (particularly Ig content) of colostrum include vaccination programs (9, 107), parity of the dam (64, 107), length of the dry period (107), and prepartum milking (107).

## Dietary Effects on Colostral Nutrient Content

In addition to its immunological value, colostrum is an excellent source of nutrition for the neonate. Colostrum contains large amounts of CP, energy, vitamins, and minerals for the calf immediately after birth.

*Energy in colostrum.* Energy in colostrum is important to the neonate immediately after birth. Calves, lambs, and pigs are born with low energy stores and generally poor insulative protection, particularly during the first few hours after birth. Colostral energy content may affect the thermoregulation and fatty acid oxidation that are necessary to sustain gluconeogenesis. Colostral fat content plays a major role in the supply of energy and in glucose homeostasis of the newborn pig (71) and is critical to proper thermoregulation (70, 96). Okamoto et al. (90) calculated that stored endogenous lipid could support summit metabolism in calves for approximately 15 h and that glycogen reserves would be depleted in ≤3 h. Heat production in calves maintained in a 10°C environment was increased by 18 and 9% in the 1st and 2nd h after colostrum consumption (131). Thus, early feeding of colostrum to provide energy and glucose or glucose precursors is critical to neonatal calves, particularly if calves are born into cold environments (41).

The manipulation of the diet to alter the fat content of bovine colostrum has not resulted in increased colostral energy content but may improve the ability of the neonate to thermoregulate. Weiss et al. (134) reported no effect from adding 200 g of fat/d for 14 d prepartum on colostral fat content. According to R. A. Bellows (1997, unpublished data), calves that were born from cows fed added safflower oil for 53 d prepartum were better able to maintain body temperature when housed at 0°C. Dietary manipulation of the colostral energy of sows is an important factor in increasing colostral fat percentage and improving pig survival (56, 71, 96). Fat content of bovine colostrum is markedly variable (36, 95, 102). Parrish et al. (95) reported that the percentage of fat in colostrum varied from 0.3 to 18.0%. Similar variability in colostral fat content has been reported more recently for Jersey cows (103). The inherent variation in colostral fat content implies a wide variation in the energy available to calves, and possibly, in their ability to establish homeostasis after birth. Research is needed to identify more completely the biological mechanisms related to fat synthesis or transport into colostrum and the importance of colostral fat to the neonate.

*Colostral protein.* Colostral proteins are utilized by the neonate for protein synthesis in addition to the absorption of Ig. Stimulation of protein metabolism after calving requires large amounts of amino acids by the neonate. Estimates of protein synthesis by newborn lambs have been reported to be 1.4 g/h per kg of BW (139). Newborn pigs that were fed colostrum had greater protein accretion in the intestine (probably because of Ig absorption) and protein synthesis in visceral organs, brain, lung, and muscle (21, 137). Burrin et al. (21) hypothesized that the intake of colostral growth factors may affect protein synthesis in neonates in addition to the availability of dietary amino acids.

Colostrum contains many proteins other than Ig. Both $\beta$-LG and $\alpha$-LA empty rapidly from the abomasum and are readily hydrolyzed to amino acids (139). Casein accumulates in the abomasum and tends to be an important, although more slowly available, source of amino acids. Although Ig are more resistant to degradation, the large mass in colostrum make this protein an important source of amino acids for the neonate. The availability of amino acids for protein synthesis and gluconeogenesis is important in establishing homeostasis in the neonate. However, calves normally absorb considerable protein during the first 24 h of life, which is usually accompanied by a transitory proteinuria. It is not clear whether modification of the prepartum diet (e.g., with ruminally protected protein or amino acids) would improve energy or protein balance of neonatal calves or improve IgG absorption. Although the production of milk protein might be increased when cows are fed ruminally protected protein or amino acids, it is not known whether the protein content of colostrum may be improved in this manner. Hook et al. (49) indicated that Holstein heifers that were fed 13% CP in ration DM did not produce more colostrum or colostrum with more IgG or IgM than heifers that were fed 9.9% CP although total protein in serum was higher for heifers that were fed higher CP diets at 1 h postpartum.

Van Saun (128) calculated that the net protein requirements of the conceptus are much greater than current estimates (88) and that current feeding recommendations may lead to the depletion of labile protein reserves in the cow. Further research is needed to evaluate the effects of dietary and undegradable protein on milk and colostral production and protein composition.

***Colostral vitamin E.*** Because α-tocopherol does not cross the placenta in appreciable amounts, the neonate is dependent upon colostral intake to obtain vitamin E after birth. The vitamin E content of colostrum is usually low unless the cow is provided supplemental dietary vitamin E (135). Hidiroglou et al. (48) reported that supplementation of the diets of gilts with 22, 44, or 88 IU of vitamin E/kg of diet increased α-tocopherol in plasma and milk, but did not alter α-tocopherol in colostrum. Other work (133, 134, 135) reported increased concentration of α-tocopherol in colostrum from cows supplemented with vitamin E. Nemec et al. (89) reported that supplemental vitamin E did not affect the absorption of colostral IgG by neonatal pigs but improved the development of cellular immunity. The addition of 0, 100, or 1000 IU of vitamin E to colostrum increased serum α-tocopherol in calves and has been proposed as a method of providing additional α-tocopherol to calves born from cows that had not been supplemented with vitamin E during the dry period (100).

The recommendation for vitamin E supplementation during the dry period to maximize colostral α-tocopherol and to minimize the incidence of postpartum metabolic disease is 1000 IU/d (133, 135). This recommendation seems suitable to maximize the disease resistance of neonates.

***Other vitamins and minerals.*** Vitamins A and D also do not cross the placenta in significant amounts, so the calf must rely on ingestion of colostrum for these vitamins. Kume and Tanabe (66) reported that serum vitamin A and β-carotene of calves increased dramatically as the time postpartum increased and that colostral vitamin A was an important source of the vitamin for neonatal calves. Supplementation of the dry cow diet with vitamin A is important to provide colostrum that contains adequate amounts of vitamin A.

Selenium readily crosses the placenta and may accumulate in fetal tissues, particularly the liver (78, 129). Swecker et al. (121) reported that dietary Se (120 mg of Se/kg of salt-mineral mix) increased colostral IgG and the absorption of colostral IgG of beef cattle. Abdelrahman and Kincaid (1) reported that calves born from cows receiving Se supplementation (3 mg of Se/d from an intraruminal bolus) had higher Se concentrations in blood and plasma and higher Se concentrations in liver at birth and at 42 d of age. Thus, the importance of proper Se supplementation of the dry cow prior to calving and ingestion of colostrum by calves is critical to providing sufficient Se to neonatal calves.

## Postnatal Ig Absorption

For many years, researchers, extension specialists, and dairy professionals have recommended early feeding of a large amount of colostrum to provide Ig prior to closure of the small intestine. Recent research has indicated the continued importance of feeding colostrum and has further refined the understanding of the importance of colostrum to the young calf. Not only does colostrum provide vital Ig, but it also provides significant amounts of immune proteins and nutrients that support the calf during the first few days of life.

Colostrum management in the US is inadequate. The National Dairy Heifer Evaluation Project conducted by the National Animal Health Monitoring System (136) reported that over 40% of all calves sampled between 24 to 48 h had IgG concentrations below the recommended level of 10 g/L and over 25% of calves had <6.2 g/L. Mortality rates of calves with serum IgG concentrations <10 g/L were over twice those of calves with higher IgG concentrations. Of course, many factors contribute to calfhood mortality, but that study (136) indicated that over half of the deaths of calves with serum IgG concentrations <10 g/L (about 40% of dairy heifer calves) was attributed to lack of IgG intake.

***Apparent efficiency of absorption.*** Serum IgG concentrations measured at 24 to 48 h of age are typically used to assess the success of the passive transfer of immunity. Many factors influence the concentration of IgG in serum, including sex of the calf, age at first feeding, BW, amount of IgG consumed, colostral quality, and others. Although serum IgG concentration is relatively easy to determine and can provide an indication of the susceptibility of the calf to disease, it does not provide information related to the dynamics of Ig absorption. For better understanding of the nature of Ig absorption and the management required to provide adequate passive immunity, it is necessary to calculate apparent efficiency of absorption (**AEA**):

$$\text{AEA (percentage)} = \text{serum IgG (grams)}/\text{IgG intake (grams)} \times 100.$$

TABLE 2. Estimates of apparent efficiency of IgG absorption.[1]

| Reference | Breed | Calculated AEA[2] | Measured blood volume? |
|---|---|---|---|
| | | (%) | |
| Kruse (65) | B & W Danish | 20 | No |
| | Red Danish | 17 | |
| | Jersey | 19 | |
| Stott and Menefee (118) | Holstein | 10 to 46 | No |
| Husband et al. (54) | Mixed | 44 (IgG$_1$) | No |
| | | 59 (IgG$_2$) | |
| Cruywagen (25) | Friesland | 43–88 | No |
| Garry et al. (38) | Holstein | 15–36 | No |
| McEwan et al. (80) | Not given | 14–54 | Yes |
| Abel and Quigley (2) | Holstein | 8–52[3] | No |
| Fike et al. (33) | Holstein | 25 | Yes |
| Hopkins and Quigley (50) | Holstein | 35 | No |
| Matte et al. (77) | Holstein | 6–66 | Yes |
| Drewry et al. (29) | Holstein | 26 | Yes |
| Morin et al. (84) | Holstein | 18–33 | No |

[1]Estimates made at 24 to 48 h of age.

[2]Apparent efficiency of IgG absorption.

[3]$\overline{X}$ = 23.

The AEA measures the efficiency with which Ig are absorbed, not the total IgG absorption. The IgG absorbed from colostrum equilibrates with other body pools; thus, AEA is an apparent measure and assumes relatively similar equilibration among animals. Calculation of the AEA requires knowledge of the mass of IgG in serum (or plasma), which in turn requires an estimate of serum (or plasma) volume:

$$\text{serum IgG (grams)} =$$
$$\text{serum IgG concentration (grams per liter)}$$
$$\times \text{ serum volume (liters)}.$$

Prediction of blood or serum volume is often carried out using dye dilution methods (79, 80). McEwan et al. (80) reported a mean plasma volume of 8.3% of BW. Others have reported mean values of 8.7 to 9.3% (79, 101) and 6.5% (82). The value of 7% of BW has been used widely in other research trials in which AEA was estimated.

***Variation in AEA.*** Reports of AEA are remarkably variable (Table 2). Because variation in AEA may affect the acquisition of passive immunity, it is important to understand how factors influence AEA. By influencing AEA, these factors may also affect serum IgG concentration:

$$\text{serum IgG concentration (grams per liter)} =$$
$$[\text{IgG intake (grams)} \times \text{AEA}]/\text{serum volume (liters)}.$$

Thus, if the AEA can be predicted with a reasonable degree of accuracy and precision, the serum IgG concentration at a given IgG intake may be predicted also.

The intake of colostral IgG has a marked influence on blood IgG concentrations. However, colostral IgG concentration influences serum IgG concentration, but does not necessarily affect AEA. At a given age, serum IgG concentration is greater in calves consuming more IgG than in calves consuming less IgG. However, the effect on serum IgG is not a function of AEA.

In most experiments (80, 116), the relationship between serum IgG and colostral IgG intake is linear, which suggests that AEA is constant throughout the range of IgG intake (Figure 1) and also suggests that the limit to absorption of IgG from the intestine is outside the range of typical IgG intake. However, others (14, 15) have reported a curvilinear relationship between IgG intake and serum IgG concentration, suggesting that there is a maximal amount of Ig that can be absorbed from the intestine. Consequently, a maximal amount of colostrum that is fed could exist that above which absorption of Ig becomes inefficient.

## Factors Affecting AEA

Many factors can influence AEA, thereby influencing the acquisition of passive immunity and possibly increasing the risk of disease. These factors include age at first colostrum feeding, sex of the calf, breed, method of colostrum feeding, and metabolic state of the calf.
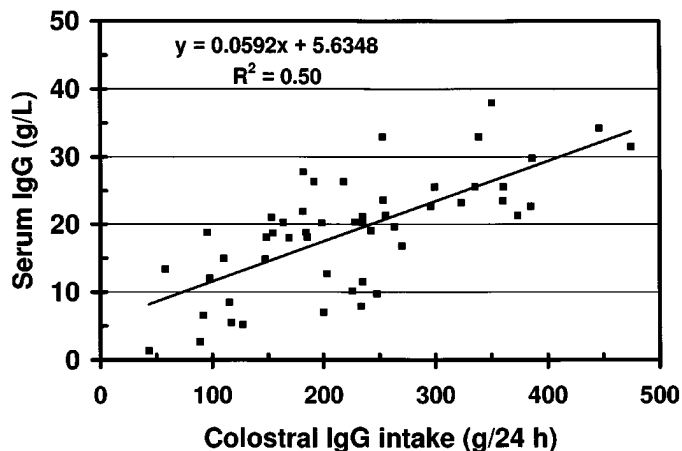


Figure 1. The relationship between colostral IgG intake and serum IgG concentration in calves. [From Hopkins and Quigley (50)].

***Age at first colostrum feeding.*** The age at which the calf is first fed colostrum has a profound effect on AEA. Current theories (58, 112) suggest that intestinal epithelial cells lose their ability to absorb intact macromolecules after about 24 h because of the maturation of the cells and the development of the intracellular digestive apparatus. This maturation begins shortly after birth. Rajala and Castrén (104) reported a decline in serum IgG concentration of 2 g/L at 30 min after birth; regression of serum IgG concentration on age at first feeding in calves fed maternal colostrum (2) also indicated a reduction of AEA within 1 h of birth. Clearly, there is a compelling reason to feed calves as soon as possible after birth to maximize the acquisition of passive immunity.

In addition to the maturation of intestinal cells, the secretion of digestive enzymes may also contribute to lower AEA by degrading IgG prior to absorption. At birth and for a limited period thereafter, the secretion of digestive enzymes remains limited to allow macromolecules such as IgG to escape digestion and allow absorption (42, 124). By about 12 h, enzyme secretion becomes more marked, thereby reducing the ability of IgG to reach the peripheral circulation without being degraded. Supplementation of colostrum with soybean trypsin inhibitor increased the absorption of IgG (102), indicating the deleterious effects of proteolytic enzymes on AEA.

Establishment of microbial populations in the intestine may also be involved in reduced AEA with time after birth. The intestinal tract of the neonate is sterile at birth; however, within a few hours, environmental bacteria begin to colonize the intestine. This colonization can be hastened by an environment that promotes the growth of pathogens (i.e., a dirty environment). James et al. (57) reported that the presence of bacteria in the intestine may actually increase the rate of intestinal closure, thereby reducing AEA and acquisition of passive immunity.

***Sex of the calf.*** The sex of the calf may influence AEA; heifer calves generally have higher serum IgG concentrations than do bull calves (107). It is not clear whether gender of the calf may be related more to blood volume than to AEA. A second possibility is that the larger size of bull calves may influence the metabolic state of the calves, thereby affecting Ig absorption. Further research in this area is warranted. However, Vann et al. (127) reported no effect of calf gender on AEA in *Bos indicus* or *Bos taurus* calves.

***Breed.*** Roy (107) summarized several studies and concluded that breed differences exist in the efficiency of Ig absorption. Holstein calves had a greater AEA than did Ayrshire calves or Friesian × Ayrshire calves. Differences in BW, gender, blood volume, metabolic state of the calf, and method of feeding have not been adequately accounted for in these studies, so the effect of breed is unclear.

***Method of colostrum feeding.*** Calves that were allowed to nurse the dam generally achieved lower serum IgG concentrations and were far more susceptible to morbidity and mortality than were calves fed colostrum by nipple bottle (19, 73). Calves that were allowed to nurse the dam often consume less colostrum than do calves fed by nipple bottles (19), thereby lowering IgG intake. In addition, calves that were allowed to nurse the dam often begin consuming colostrum later than do calves fed by nipple bottle, thereby lowering AEA by allowing maturation of the intestinal epithelium.

Research that has controlled (or measured) the intake of IgG by calves that were allowed to nurse the dam early have reported AEA that was better than for calves fed by nipple bottle (108, 117). Those researchers (108, 117) have hypothesized that a neural effect of the presence of the dam or some labile component in colostrum may be responsible for improved AEA in the calf.

The use of the esophageal feeder to feed large quantities of colostrum has been associated with reduced AEA and slightly lower serum IgG concentration compared with colostrum administered by nipple bottle (72). Colostrum administered by esophageal feeder enters the rumen before moving into the abomasum and intestine (69). Thereafter, it takes 2 to 4 h for the colostrum to leave the rumen. This interval may actually be the reason for lower AEA, because the intestine may mature during this time, thereby reducing the number of actively absorbing cells in the intestine. However, many veterinarians recommend feeding 4 L of colostrum as soon as possible after birth to ensure that all colostrum is consumed. Others (3, 81) support the use of esophageal feeders to provide large amounts of colostrum without significant effect on serum IgG concentrations.

***Metabolic state of the calf.*** A strong correlation exists between perinatal mortality in the calf caused by metabolic or respiratory acidosis (123), which is common at birth (16, 37, 123). Some researchers (37, 61, 123) view this relationship as physiological, but others (16, 18) consider it to be abnormal and a threat to the health and survival of the neonate. The prevalence of respiratory acidosis immediately postpartum could inhibit the ability of the neonate to adapt to the extrauterine environment. Normal birth is generally accompanied by a brief period of hypoxia

or ischemia. Often the increase in $P_{CO_2}$ lowers pH, resulting in mild acidosis (37). Metabolic, respiratory, and mixed acidosis occur frequently, but significant alkalosis is rarely observed (37). Risk factors associated with postnatal acidosis include the duration of observed second stage labor >2 h, dystocia requiring traction, and weakness of a calf at birth (16). Mean arterial $P_{CO_2}$ concentrations range from 43 to 59 mm Hg (4, 30). By comparison, normal arterial $P_{CO_2}$ in adult mammals that are awake ranges from 35 to 45 mm Hg (62). Mean venous $P_{CO_2}$ concentrations in healthy calves not exhibiting respiratory distress syndrome were $58 \pm 2$ mm Hg (123).

Garry (37) determined that mean arterial $P_{CO_2}$ concentrations fell with the onset of steady respiration; adult concentrations are usually achieved by 24 to 48 h (47, 62). Neonates have internal homeostatic mechanisms compensating somewhat for the alterations in blood pH, $P_{CO_2}$, $HCO_3^-$ concentration and base excess or deficit at and immediately after birth (37, 114). Other research indicates the metabolic ($HCO_3^-$ concentration or base excess or deficit) portion resolves within the first 4 h of life, but the respiratory portion ($P_{CO_2}$) prevails as an abnormality for $\geq 48$ h (16, 18). Calves experiencing acidotic conditions resulting from increased $P_{CO_2}$ may compensate for increased $P_{CO_2}$ by as late as 48 h (16, 18, 61), which commonly is referred to as respiratory acidosis because the respiratory component $CO_2$, and not the metabolic component, $HCO_3^-$, is the factor altering pH.

***Respiratory acidosis.*** Respiratory acidosis may affect AEA and the acquisition of passive immunity. Although metabolic acidosis usually resolves within 2 h of birth, respiratory acidosis may persist for >24 h (16, 18). Serum $IgG_1$ concentrations may be reduced in calves that have a lower blood pH and elevated $P_{CO_2}$ (16). Boyd (18) reported that birth $P_{CO_2}$, but not pH, was inversely correlated to serum $IgG_1$ concentrations. Conversely, several others (8, 29, 74, 120) did not find a significant relationship between $P_{CO_2}$ (arterial or venous) and plasma IgG concentration or AEA in calves. Tyler and Ramsey (126) suggested that hypoxia occurring in calves immediately after birth might delay the absorption of IgG but not affect peak plasma IgG concentration.

Calves born from cows that were fed anionic diets might be affected by respiratory or metabolic acidosis, which might, in turn, affect AEA (44, 60). Conversely, Tucker et al. (125) reported that the cation-anion balance of the diet (either −30 or +90 meq/kg of DM) consumed by 120 dry cows and heifers did not affect the acid-base status or the plasma mineral content of their calves. Guy et al. (44) reported increased serum $IgG_1$ concentrations when calves were fed an oral paste of sodium bicarbonate 0.5 h after the first colostrum feeding. Calves were born from cows that were fed diets with a dietary cation-anion difference of +445 or +75 meq/kg of DM for 3 wk prepartum. Calves that were born from cows fed the cationic diet had higher serum $IgG_1$ concentration at 24 h than did calves from cows fed more acidotic diets, although venous blood $P_{CO_2}$ was not affected (44).

Conversely, Ayers and Besser (8) reported no improvement in serum $IgG_1$ concentration of calves injected with either doxapram·HCl (2 mg/kg of BW) or sodium bicarbonate (3 meq/kg of BW), although pH was increased, and $P_{CO_2}$ was decreased by treatment with doxapram HCl alone or in combination with sodium bicarbonate. Further research is required to determine the total effect of neonatal acid-base status on the ability of the calf to absorb colostral Ig and to determine whether treatments are effective or necessary.

Research (30, 83, 123) using mammals often reports blood gas concentrations obtained from venous samples. Venous samples are less satisfactory than arterial samples for $P_{CO_2}$ measurements and should be restricted to evaluating metabolic conditions (111). Effects of regional metabolism and circulation on venous blood alter $CO_2$ tension and pH in an unpredictable manner so that the respiratory contribution cannot be accurately assessed (27). Furthermore, peripheral venous samples are often taken while the vein is engorged with nonflowing blood, which may artificially increase $P_{CO_2}$ and reduce pH (34, 123). Blood gas measurements using arterial blood is the only practical method of monitoring changes in respiratory function, oxygenation, and metabolic acid-base balance (4, 34).

***Effects of environment.*** The absorption of Ig may be affected by the environment in which the calf is born. Extreme cold (93), but not moderate cold (91, 94), reduces the absorption of Ig by calves. The effects of ambient temperature outside the thermoneutral range for calves might involve direct effects

on intestinal absorption and transport (91) as well as the ability of the calf to stand and nurse (92, 113).

***Stress hormones.*** The degree of dystocia may affect survival of calves. The relationship between dystocia and lower plasma Ig concentrations has been determined (28). However, research by Stott and Rienhardt (119) suggested that dystocia did not influence concentrations of circulating cortisol concentrations or affect AEA. Concentrations of glucocorticoids affect absorption of Ig in calves. Administration of ACTH has been reported to increase IgG absorption in calves (59, 115) but may be dependent upon the degree of maturation of the calf at birth (115).

***Colostral IgG concentration.*** The concentration of IgG in colostrum may influence AEA. Stott and Fellah (116) reported that calves fed 1 L of colostrum containing various amounts of IgG were more efficient in absorbing IgG than were calves fed the same mass of IgG in 2 L. Stott and Fellah (116) also suggested that large amounts of colostrum containing a low concentration of IgG would not be absorbed adequately; instead, limited amounts of high IgG colostrum may be more important. The ability of the intestine to extract Ig from colostrum may be improved when more concentrated (higher Ig) colostrum is fed. However, other research is needed to confirm this finding.

***Amount of colostrum fed.*** Concentration of Ig in colostrum from the first milking may be inadequate to ensure the transfer of an adequate mass of Ig when ≤2 L are fed. Besser et al. (14) suggested that the prevalence of failure of passive transfer in dairy herds could be minimized by artificially feeding calves large volumes (3 to 4 L) of fresh or refrigerated colostrum within the first 24 h. It is not clear whether the absorption of Ig in calves is affected by feeding a similar volume of colostrum in one or two feedings. Halliday and Williams (46) reported that one feeding of colostrum fed to lambs reduced AEA compared with results for two feedings that were 6 h apart. Increased serum IgG concentrations were attributed to improved absorption of the first feeding as a result of the second. Recent research (50) suggests that absorption of IgG is similar whether calves are fed 4 L in one or two feedings.

## CONCLUSIONS

Nutrition and management of the cow during the dry period may have a profound effect on the survival, health, and growth of newborn calves. The proper management of energy intake to control body condition from late lactation until calving minimizes the potential for harmful effects of nutrient deprivation or overconditioning and dystocia on newborn calves. Dry cow diets should be supplemented with vitamins and minerals to improve the quality of colostrum. Further research is indicated to define better the relationship between the anion content of the diet and the incidence of respiratory or metabolic acidosis in neonates and acquisition of passive immunity.

## REFERENCES

1 Abdelrahman, M. M., and R. L. Kincaid. 1995. Effect of selenium supplementation of cows on maternal transfer of selenium to fetal and newborn calves. J. Dairy Sci. 78:625–630.
2 Abel Francisco, S. F., and J. D. Quigley, III. 1993. Serum immunoglobulin concentration in response to maternal colostrum and colostral supplementation in dairy calves. Am. J. Vet. Res. 54:1051–1054.
3 Adams, G. D., L. J. Bush, J. L. Horner, and T. E. Staley. 1985. Two methods for administering colostrum to newborn calves. J. Dairy Sci. 68:773–775.
4 Adams, R., R. B. Garry, B. M. Aldridge, M. D. Holland, and K. G. Odde. 1993. Physiologic differences between twin and single born beef calves in the first two days of life. Cornell Vet. 83:13–29.
5 Alexander, G. 1962. Temperature regulation in the newborn lamb. Aust. J. Agric. Res. 13:100–121.
6 Alexander, G. 1962. Energy metabolism in the starved newborn lamb. Aust. J. Agric. Res. 13:144–164.
7 Al-Sabbagh, T. A., L. V. Swanson, and J. M. Thompson. 1995. The effect of ewe body condition at lambing on colostral immunoglobulin G concentration and lamb performance. J. Anim. Sci. 73:2860–2864.
8 Ayers, M. W., and T. E. Besser. 1992. Evaluation of colostral IgG1 absorption in newborn calves after treatment with alkalinizing agents. Am. J. Vet. Res. 53:83–86.
9 Barringer, L. S., and J. B. Resenberg. 1995. Better colostrum. Large Anim. Vet. 50:22.
10 Bell, A. W. 1995. Regulation of organic nutrient metabolism during transition from late pregnancy to early lactation. J. Anim. Sci. 73:2804–2819.
11 Bell, A. W., M. B. Rymph, R. Slepetis, W. A. House, and R. A. Ehrhardt. 1992. Net nutrient requirements for conceptus growth in Holstein cows—implications for dry cow feeding. Pages 102–109 in Proc. Cornell Nutr. Conf. Feed Manuf., Rochester, NY. Cornell Univ., Ithaca, NY.
12 Bell, A. W., R. Slepetis, and R. A. Ehrhardt. 1995. Growth and accretion of energy and protein in the gravid uterus during late pregnancy. J. Dairy Sci. 78:1954–1961.
13 Bellows, R. A., and R. E. Short. 1978. Effects of precalving feed level on birth weight, calving difficulty, and subsequent fertility. J. Anim. Sci. 46:1522–1528.
14 Besser, T. E., A. E. Garmedia, T. C. McGuire, and C. C. Gay. 1985. Effect of colostral immunoglobulin G1 and immunoglobulin M concentrations on immunoglobulin absorption in calves. J. Dairy Sci. 68:2033–2037.
15 Besser, T. E., C. C. Gay, and L. Pritchett. 1991. Comparison of three methods of feeding colostrum to dairy calves. JAVMA 198:419–422.
16 Besser, T. E., O. Szenci, and C. C. Gay. 1990. Decreased colostral immunoglobulin absorption in calves with postnatal respiratory acidosis. JAVMA 196:1239–1243.
17 Blecha, F., R. C. Bull, D. P. Olson, R. H. Ross, and S. Curtis. 1981. Effects of prepartum protein restriction in the beef cow on immunoglobulin content in blood and colostral whey and subsequent immunoglobulin absorption by the neonatal calf. J. Anim. Sci. 53:1174–1180.

18 Boyd, J. W. 1989. Relationships between acid-base balance, serum composition and colostrum absorption in newborn calves. Br. Vet. J. 145:249–256.

19 Brignole, T. J., and G. H. Stott. 1980. Effect of suckling followed by bottle feeding colostrum on immunoglobulin absorption and calf survival. J. Dairy Sci. 63:451–456.

20 Bull, R. C., R. R. Loucks, F. L. Edminston, J. N. Hawkins, and E. H. Stauber. 1974. Nutrition and weak calf syndrome in beef cattle. Univ. Idaho Current Info. Serv. No. 246. Univ. Idaho, Boise.

21 Burrin, D. G., R. J. Shulman, P. J. Reeds, T. A. Davis, and K. R. Gravitt. 1992. Porcine colostrum and milk stimulate visceral organ and skeletal muscle protein synthesis in neonatal pigs. J. Nutr. 122:1205–1213.

22 Burton, J. H., A. A. Hosein, D. G. Grieve, and B. N. Wilkie. 1984. Immunoglobulin absorption in calves as influenced by dietary protein intakes of their dams. Can. J. Anim. Sci. 64(Suppl.):185–186.(Abstr.)

23 Carstens, G. E., D. E. Johnson, M. D. Holland, and K. G. Odde. 1987. Effects of prepartum protein restriction and birth weight on basal metabolism in bovine neonates. J. Anim. Sci. 65: 745–751.

24 Corah, L. R., T. G. Dunn, and C. C. Kaltenbach. 1975. Influence of prepartum nutrition on the reproductive performance of beef females and the performance of their progeny. J. Anim. Sci. 41:819–824.

25 Cruywagen, C. W. 1990. Effect of curd forming of colostrum on absorption of immunoglobulin G in newborn calves. J. Dairy Sci. 73:3287–3290.

26 Curtis, C. R., H. H. Erb, C. J. Sniffen, R. D. Smith, and D. S. Kronfeld. 1985. Path analysis of dry period nutrition, postpartum metabolic and reproductive disorders, and mastitis in Holstein cows. J. Dairy Sci. 68:2347–2360.

27 Donawick, W. J., and A. E. Baue. 1968. Blood gases, acid-base balance, and alveolar-arterial oxygen gradient in calves. Am. J. Vet. Res. 29:561–567.

28 Donovan, G. A., L. Bading, R. J. Collier, C. J. Wilcox, and R. K. Braun. 1986. Factors influencing passive transfer in dairy calves. J. Dairy Sci. 69:754–579.

29 Drewry, J. J., and J. D. Quigley, III. 1997. Effects of respiratory acidosis on apparent efficiency of IgG absorption in calves. J. Dairy Sci. 80(Suppl. 1):143.(Abstr.)

30 Eigenmann, U.J.E., H. A. Schoon, D. Jahn, and E. Grunert. 1984. Neonatal respiratory distress syndrome in the calf. Vet. Rec. 114:141–144.

31 Eley, R. M., W. W. Thatcher, F. W. Bazer, C. J. Wilcox, R. B. Becker, H. H. Head, and R. W. Adkinson. 1978. Development of the conceptus in the bovine. J. Dairy Sci. 61:467–473.

32 Ferrell, C. L., W. N. Garrett, and N. Hinman. 1976. Growth, development and composition of the udder and gravid uterus of beef heifers during pregnancy. J. Anim. Sci. 42:1477–1489.

33 Fike, D., M. Egerton, J. D. Quigley, III, and J. J. Drewry. 1997. Apparent efficiency of IgG absorption in calves fed pooled colostrum or a colostrum supplement. J. Dairy Sci. 80(Suppl. 1):214.(Abstr.)

34 Filley, G. F. 1971. Acid-Base and Blood Gas Regulation for Medical Students Before and After Graduation. Lea and Febiger, Philadelphia, PA.

35 Fishwick, G., and D. Clifford. 1975. The effects of a low protein intake by beef cows during pregnancy on the voluntary intake of roughage, the composition of the colostrum and the serum immune globulin concentration of their calves. Proc. Nutr. Soc. 34:74A.(Abstr.)

36 Foley, J. A., and D. E. Otterby. 1978. Availability, storage, treatment, composition, and feeding value of surplus colostrum: a review. J. Dairy Sci. 61:1033–1060.

37 Garry, F. B. 1993. Clinical aspects of acidosis in newborn calves. Pages 60–64 in Proc. 3rd Int. Conf. Vet. Perinat., Davis, CA.

38 Garry, F. B., R. Adams, M. B. Cattell, and R. P. Dinsmore. 1996. Comparison of passive immunoglobulin transfer to dairy calves fed colostrum or commercially available colostral-supplement products. JAVMA 208:107–110.

39 Gearhart, M. A., C. R. Curtis, H. N. Erb, R. D. Smith, C. J. Sniffen, L. E. Chase, and M. D. Cooper. 1990. Relationship of changes in condition score to cow health in Holsteins. J. Dairy Sci. 73:3132–3140.

40 Gerloff, B. J. 1988. Feeding the dry cow to avoid metabolic disease. Vet. Clin. North Am. Food Anim. Pract. 4:379–390.

41 Godfrey, R. W., S. D. Smith, M. J. Guthrie, R. L. Stanko, D. A. Neuendorff, and R. D. Randel. 1991. Physiological responses of newborn Bos indicus and Bos indicus × Bos taurus calves after exposure to cold. J. Anim. Sci. 69:258–263.

42 Guilloteau, P., T. Corring, P. Garnot, P. Martin, R. Toullec, and D. Durand. 1983. Effects of age and weaning on enzyme activities of abomasum and pancreas of the lamb. J. Dairy Sci. 66:2373–2385.

43 Guy, M. A., T. B. McFadden, D. C. Cockrell, and T. E. Besser. 1994. Effects of unilateral prepartum milking on concentrations of immunoglobulin $G_1$ and prolactin in colostrum. J. Dairy Sci. 77:3584–3591.

44 Guy, M. A., W. K. Sanchez, J. J. Higgins, R. L. Crill, and J. G. Giesy. 1996. Effect of an oral paste of sodium bicarbonate given at parturition on immunoglobulin status of neonatal calves. J. Dairy Sci. 79(Suppl. 1):198.(Abstr.)

45 Halliday, R., A.J.F. Russel, M. R. Williams, and J. N. Peart. 1978. Effects of energy intake during late pregnancy and of genotype on immunoglobulin transfer to calves in suckler herds. Res. Vet. Sci. 24:26–31.

46 Halliday, R., and M. R. Williams. 1976. Passive immunity in the lamb. Effects of a second feed of colostrum on antibody absorption from the first feed. Res. Vet. Sci. 21:173–175.

47 Haskins, S. C. 1977. An overview of acid-base physiology. JAVMA 170:423–427.

48 Hidiroglou, M., E. Farnworth, and G. Butler. 1993. Effects of vitamin E and fat supplementation on concentration of vitamin E in plasma and milk of sows and in plasma of piglets. Int. J. Vitam. Nutr. Res. 63:180–187.

49 Hook, T. E., K. G. Odde, A. A. Aguilar, and J. D. Olson. 1989. Protein effects on fetal growth, colostrum and calf immunoglobulins and lactation in dairy heifers. J. Anim. Sci. 67(Suppl. 1):539.(Abstr.)

50 Hopkins, B. A., and J. D. Quigley, III. 1997. Effects of method of colostrum feeding and colostral supplementation on serum IgG concentrations in neonatal calves. J. Dairy Sci. 80: 979–983.

51 Hough, R. L., F. D. McCarthy, H. D. Kent, D. E. Eversole, and M. L. Wahlberg. 1990. Influence of nutritional restriction during late gestation on production measures and passive immunity in beef cattle. J. Anim. Sci. 68:2622–2627.

52 House, W. A., and A. W. Bell. 1993. Mineral accretion in the fetus and adnexa during late gestation in Holstein cows. J. Dairy Sci. 76:2999–3010.

53 House, W. A., and A. W. Bell. 1994. Sulfur and selenium accretion in the gravid uterus during late gestation in Holstein cows. J. Dairy Sci. 77:1860–1869.

54 Husband, A. J., M. R. Brandon, and A. K. Lascelles. 1972. Absorption and endogenous production of immunoglobulins in calves. Aust. J. Exp. Biol. Med. Sci. 50:491–498.

55 Hutjens, M. F. 1996. Practical approaches to feeding the high producing cow. Anim. Feed Sci. Technol. 59:199–206.

56 Jackson, J. R., W. L. Hurley, R. A. Easter, A. H. Jensen, and J. Odle. 1995. Effects of induced or delayed parturition and supplemental dietary fat on colostrum and milk composition in sows. J. Anim. Sci. 73:1906–1913.

57 James, R. E., C. E. Polan, and K. A. Cummins. 1981. Influence of administered indigenous microorganisms on uptake of $I^{125}$-γ-globulin in vivo by intestinal segments of neonatal calves. J. Dairy Sci. 64:52–61.

58 Jochims, K., F. J. Kaup, W. Drommer, and M. Pickel. 1994. An immunoelectron microscopic investigation of colostral IgG absorption across the intestine of newborn calves. Res. Vet. Sci. 57:75–80.

59 Johnston, N. E., and W. D. Oxender. 1979. Effect of altered serum glucocorticoid concentrations on the ability of the newborn calf to absorb colostral immunoglobulin. Am. J. Vet. Res. 40:32–34.

60 Joyce, P. W., and W. K. Sanchez. 1994. Dietary cation-anion difference and forage type during the dry period: effect on lactational performance and metabolic disorders of cows and health of calves. J. Dairy Sci. 77(Suppl. 1):97.(Abstr.)

61 Kasari, T. R. 1994. Physiologic mechanisms of adaptation in the fetal calf at birth. Vet. Clin. North Am. Food Anim. Pract. 10:127–136.

62 Kirk, R. W. 1983. Current Veterinary Therapy VIII: Small Animal Practice. W. B. Saunders Co., Philadelphia, PA.

63 Koritnik, D. R., W. D. Humphrey, C. C. Kaltenbach, and T. G. Dunn. 1981. Effects of maternal undernutrition on the development of the ovine fetus and the associated changes in growth hormone and prolactin. Biol. Reprod. 24:125–137.

64 Kruse, V. 1970. Yield of colostrum and immunoglobulin in cattle at the first milking after parturition. Anim. Prod. 12:619–626.

65 Kruse, V. 1970. Absorption of immunoglobulin from colostrum in newborn calves. Anim. Prod. 12:627–638.

66 Kume, S., and S. Tanabe. 1993. Effect of parity of Holstein cows on vitamin A and beta-carotene concentrations of colostrum and calf serum. Anim. Sci. Technol. 64:987–991.

67 Laster, D. B. 1974. Factors affecting pelvic size and dystocia in beef cattle. J. Anim. Sci. 38:496–503.

68 Laster, D. B., H. H. Glimp, L. V. Cundiff, and K. E. Gregory. 1973. Factors affecting dystocia and the effects of dystocia on subsequent reproduction in beef cattle. J. Anim. Sci. 36:695–705.

69 Lateur-Rowet, H.J.M., and H. J. Breuink. 1983. The failure of the oesophageal groove reflex, when fluids are given with an oesophageal feeder to newborn and young calves. Vet. Q. 5:68–74.

70 Le Dividich, J., T. Esnault, B. Lynch, R. Hoo-Paris, C. Castex, and J. Peiniau. 1991. Effect of colostral fat level on fat deposition and plasma metabolites in the newborn pig. J. Anim. Sci. 69:2480–2488.

71 Le Dividich, J., P. Herpin, and R. M. Rosario-Ludovino. 1994. Utilization of colostral energy by the newborn pig. J. Anim. Sci. 72:2082–2089.

72 Lee, R. B., T. E. Besser, C. C. Gay, and T. C. McGuire. 1983. The influence of method of feeding on IgG concentrations acquired by calves. Pages 373–377 in Proc. 4th Int. Symp. Neonatal Diarrhea. Vet. Infect. Dis. Organ, Saskatoon, SK, Canada.

73 Logan, E. F., B. D. Muskett, and R. J. Herron. 1981. Colostrum feeding of dairy calves. Vet. Rec. 108:283–284.

74 López, A., J. Löfstedt, R. Bildfell, B. Horney, and S. Burton. 1994. Pulmonary histopathological findings, acid-base status, and absorption of colostral immunoglobulins in newborn calves. Am. J. Vet. Res. 55:1303–1307.

75 Mangurkar, B. R., J. F. Hayes, and J. E. Moxley. 1984. Effects of calving ease-calf survival on production and reproduction in Holsteins. J. Dairy Sci. 67:1496–1509.

76 Martinez, M. L., A. E. Freeman, and P. J. Berger. 1983. Genetic relationships between calf livability and calving difficulty in Holsteins. J. Dairy Sci. 66:1494–1502.

77 Matte, J. J., C. L. Girard, J. R. Seoane, and G. J. Brisson. 1982. Absorption of colostral immunoglobulin G in the newborn dairy calf. J. Dairy Sci. 65:1765–1770.

78 McDowell, L. R., S. N. Williams, N. Hidiroglou, C. A. Njeru, G. M. Hill, L. Ochoa, and N. S. Wilkinson. 1996. Vitamin E supplementation for the ruminant. Anim. Feed Sci. Technol. 60:273–296.

79 McEwan, A. D., E. W. Fisher, and I. E. Selman. 1968. The effect of colostrum on the volume and composition of the plasma of calves. Res. Vet. Sci. 9:284–286.

80 McEwan, A. D., E. W. Fisher, and I. E. Selman. 1970. An estimation of the efficiency of the absorption of immune globulins from colostrum by newborn calves. Res. Vet. Sci. 11:239–243.

81 Molla, A. 1978. Immunoglobulin levels in calves fed colostrum by stomach tube. Vet. Rec. 103:377–380.

82 Möllerberg, L., L. Ekman, and S. O. Jacobsson. 1975. Plasma and blood volume in the calf from birth till 90 days of age. Acta Vet. Scand. 16:178–185.

83 Moore, W. E. 1969. Acid-base and electrolyte changes in normal calves during the neonatal period. Am. J. Vet. Res. 30:1133–1138.

84 Morin, D. E., G. C. McCoy, and W. L. Hurley. 1997. Effects of quality, quantity, and timing of colostrum feeding and addition of a dried colostrum supplement on immunoglobulin $G_1$ absorption in Holstein bull calves. J. Dairy Sci. 80:747–753.

85 Morrow, D. A. 1976. Fat cow syndrome. J. Dairy Sci. 59:1625–1629.

86 Muller, L. D. 1992. Feeding management strategies. Page 326 in Large Dairy Herd Management. H. H. Van Horn and C. J. Wilcox, ed. Am. Dairy Sci. Assoc., Champaign, IL.

87 Nardone, A., N. Lacetera, U. Bernabucci, and B. Ronchi. 1997. Composition of colostrum from dairy heifers exposed to high air temperatures during late pregnancy and the early postpartum period. J. Dairy Sci. 80:838–844.

88 National Research Council. 1989. Nutrient Requirements of Dairy Cattle. 6th rev. ed. Natl. Acad. Sci, Washington, DC.

89 Nemec, M., G. Butler, M. Hidiroglou, E. R. Farnworth, and K. Nielsen. 1994. Effect of supplementing gilts' diets with different levels of vitamin E and different fats on the humoral and cellular immunity of gilts and their progeny. J. Anim. Sci. 72:665–676.

90 Okamoto, M., J. B. Robinson, R. J. Christopherson, and B. A. Young. 1986. Summit metabolism of newborn calves with and without colostrum feeding. Can. J. Anim. Sci. 66:937–944.

91 Olson, D. P., R. C. Bull, L. F. Woodward, and K. W. Kelley. 1981. Effects of maternal nutritional restriction and cold stress on young calves: absorption of colostral immunoglobulins. Am. J. Vet. Res. 42:876–880.

92 Olson, D. P., C. J. Papasian, and R. C. Ritter. 1980. The effects of cold stress on neonatal calves. 1. Clinical condition and pathological lesions. Can. J. Comp. Med. 44:11–18.

93 Olson, D. P., C. J. Papasian, and R. C. Ritter. 1980. The effects of cold stress on neonatal calves. 2. Absorption of colostrum immunoglobulins. Can. J. Comp. Med. 44:19–23.

94 Olson, D. P., L. F. Woodward, R. C. Bull, and D. O. Everson. 1981. Immunoglobulin levels in serum and colostral whey of protein-metabolizable energy restricted beef cows. Res. Vet. Sci. 30:49–52.

95 Parrish, D. B., G. H. Wise, J. S. Hughes, and F. W. Atkeson. 1950. Properties of the colostrum of the dairy cow. V. Yield, specific gravity, and concentrations of total solids and its various components of colostrum and early milk. J. Dairy Sci. 33:457–465.

96 Pettigrew, J. 1981. Supplemental dietary fat for peripartal sows: a review. J. Anim. Sci. 53:107–117.

97 Pollack, E. J., and A. E. Freeman. 1976. Parameter estimation and sire evaluation for dystocia and calf size in Holsteins. J. Dairy Sci. 59:1817–1824.

98 Prior, R. L., and D. B. Laster. 1979. Development of the bovine fetus. J. Anim. Sci. 48:1546–1553.

99 Pritchett, L. C., C. C. Gay, T. E. Besser, and D. Hancock. 1991. Management and production factors influencing immunoglobulin $G_1$ concentration in colostrum from Holstein cows. J. Dairy Sci. 74:2336–2341.

100 Quigley, J. D., III, and J. K. Bernard. 1995. Effects of addition of vitamin E to colostrum on serum $\alpha$-tocopherol and immunoglobulin concentrations in neonatal calves. Food Agric. Immunol. 7:295–298.

101 Quigley, J. D., III, J. J. Drewry, and K. R. Martin. 1998. Estimation of plasma volume in Holstein and Jersey calves. J. Dairy Sci. 81:1308–1312.

102 Quigley, J. D., III, K. R. Martin, H. H. Dowlen, and K. C. Lamar. 1995. Addition of soybean trypsin inhibitor to bovine

colostrum: Effects on serum immunoglobulin concentrations in Jersey calves. J. Dairy Sci. 78:886–892.

103 Quigley, J. D., III, K. R. Martin, H. H. Dowlen, L. B. Wallis, and K. Lamar. 1994. Immunoglobulin concentration, specific gravity, and nitrogen fractions of colostrum from Jersey cattle. J. Dairy Sci. 77:264–269.

104 Rajala, P., and H. Castrén. 1995. Serum immunoglobulin concentrations and health of dairy calves in two management systems from birth to 12 weeks of age. J. Dairy Sci. 78: 2737–2744.

105 Rattray, P. V., W. N. Garrett, N. E. East, and N. Hinman. 1974. Growth, development and composition of the ovine conceptus and mammary gland during pregnancy. J. Anim. Sci. 38:613–626.

106 Rattray, P. V., D. W. Robinson, W. N. Garrett, and R. C. Ashmore. 1975. Cellular changes in the tissues of lambs during fetal growth. J. Anim. Sci. 40:783–788.

107 Roy, J.H.B. 1990. The Calf. Vol. I. Management of Health. Butterworths, Boston, MA.

108 Selman, I. E., A. D. McEwan, and E. W. Fisher. 1970. Serum immune globulin concentration of calves left with their dams for the first two days of life. J. Comp. Pathol. 80:419–427.

109 Sieber, M., A. E. Freeman, and D. H. Kelley. 1989. Effects of body measurements and weight on calf size and calving difficulty of Holsteins. J. Dairy Sci. 72:2402–2410.

110 Sivula, N. J., T. R. Ames, and W. E. Marsh. 1996. Management practices and risk factors for morbidity and mortality in Minnesota dairy heifer calves. Prev. Vet. Med. 27:173–182.

111 Smith, B. P. 1996. Large Animal Internal Medicine. 2nd ed. Mosby Press, St. Louis, MO.

112 Staley, T. E., and L. J. Bush. 1985. Receptor mechanisms of the neonatal intestine and their relationship to immunoglobulin absorption and disease. J. Dairy Sci. 68:184–205.

113 Stauber, E. H. 1976. Weak calf syndrome: a continuing enigma. JAVMA 168:223–225.

114 Stewart, J. G., R. J. Rose, and A. M. Barko. 1984. Respiratory studies in foals from birth to seven days old. Equine Vet. J. 16: 323–328.

115 Stott, G. H. 1980. Immunoglobulin absorption in calf neonates with special consideration of stress. J. Dairy Sci. 63:681–688.

116 Stott, G. H., and A. Fellah. 1983. Colostral immunoglobulin absorption linearly related to concentration for calves. J. Dairy Sci. 66:1319–1328.

117 Stott, G. H., D. B. Marx, B. E. Menefee, and G. T. Nightengale. 1979. Colostral immunoglobulin transfer in calves. IV. Effect of suckling. J. Dairy Sci. 62:1908–1913.

118 Stott, G. H., and B. E. Menefee. 1978. Selective absorption of immunoglobulin M in the newborn calf. J. Dairy Sci. 61: 461–466.

119 Stott, G. H., and E. J. Rienhard. 1978. Adrenal function and passive immunity in the dystocial calf. J. Dairy Sci. 61: 1457–1461.

120 Strawn, K. 1996. Effects of birth stress in calves. M.S. Thesis, Iowa State Univ., Ames.

121 Swecker, W. S., C. D. Thatcher, D. E. Eversole, D. J. Blodgett, and G. S. Schurig. 1995. Effect of selenium supplementation on colostral IgG concentration in cows grazing selenium-deficient pastures and on postsuckle serum IgG concentration in their calves. Am. J. Vet. Res. 56:450–453.

122 Sykes, A. R., and A. C. Field. 1972. Effects of dietary deficiencies of energy, protein and calcium on the pregnant ewe. II. Body composition and mineral content of the lamb. J. Agric. Sci. (Camb.) 78:119–125.

123 Szenci, O. 1985. Role of acid-base disturbances in perinatal mortality of calves. Acta Vet. Hung. 33:205–220.

124 Thivend, P., R. Toulec, and P. Guilloteau. 1980. Digestive adaptation in the preruminant. Pages 561–569 *in* Digestive Physiology and Metabolism in Ruminants. Y. Ruckebusch and P. Thivend, ed. AVI Publ. Co., Westport, CT.

125 Tucker, W. B., J. F. Hogue, G. D. Adams, M. Aslam, I. S. Shin, and G. Morgan. 1992. Influence of the dietary cation-anion balance during the dry period on the occurrence of parturient paresis in cows fed excess calcium. J. Anim. Sci. 70:1238–1250.

126 Tyler, H., and H. Ramsey. 1991. Hypoxia in neonatal calves: effect on intestinal transport of immunoglobulins. J. Dairy Sci. 74:1953–1956.

127 Vann, R. C., J. W. Holloway, G. E. Carstens, M. E. Boyd, and R. D. Randel. 1995. Influence of calf genotype on colostral immunoglobulins in *Bos taurus* and *Bos indicus* cows and serum immunoglobulins in their calves. J. Anim. Sci. 73: 3044–3050.

128 Van Saun, R. J. 1991. Dry cow nutrition: the key to improving fresh cow performance. Vet. Clin. North Am. Food Anim. Pract. 7:599–620.

129 Van Saun, R. J., T. H. Herdt, and H. D. Stowe. 1989. Maternal and fetal selenium concentrations and their inter-relationships in dairy cattle. J. Nutr. 119:1128–1137.

130 Van Saun, R. J., and C. J. Sniffen. 1996. Nutritional management of the pregnant dry cow to optimize health, lactation and reproductive performance. Anim. Feed Sci. Technol. 59:13–26.

131 Vermorel, M., C. Dardillat, J. Vernet, S. Saido, and C. Demigne. 1983. Energy metabolism and thermoregulation in the newborn calf. Ann. Rech. Vet. 14:382–389.

132 Warrington, B. F., F. M. Byers, G. T. Schelling, J. F. Baker, and L. W. Greene. 1985. Heifer and calf growth as affected by prepartum energy levels. J. Anim. Sci. 61(Suppl. 1): 458.(Abstr.)

133 Weiss, W. P., J. S. Hogan, K. L. Smith, D. A. Todhunter, and S. N. Williams. 1992. Effect of supplementing periparturient cows with vitamin E on distribution of $\alpha$-tocopherol in blood. J. Dairy Sci. 75:3479–3485.

134 Weiss, W. P., J. S. Hogan, K. L. Smith, and S. N. Williams. 1994. Effect of dietary fat and vitamin E on $\alpha$-tocopherol and $\beta$-carotene in blood of peripartum cows. J. Dairy Sci. 77: 1422–1429.

135 Weiss, W. P., D. A. Todhunter, J. S. Hogan, and K. L. Smith. 1990. Effect of duration of supplementation of selenium and vitamin E on periparturient dairy cows. J. Dairy Sci. 73: 3187–3194.

136 Wells, S. J., D. A. Dargatz, and S. L. Ott. 1996. Factors associated with mortality to 22 days of life in dairy herds in the United States. Prev. Vet. Med. 29:9–19.

137 Widdowson, E. M., and D. E. Crabb. 1976. Changes in the organs of pigs in response to feeding for the first 24 h after birth. I. The internal organs and muscles. Biol. Neonate 28: 261–271.

138 Winger, K., C. C. Gay, and T. E. Besser. 1995. Immunoglobulin G$_1$ transfer into induced mammary secretions: the effect of dexamethasone. J. Dairy Sci. 78:1306–1309.

139 Yvon, M., D. Levieux, M. Valluy, J. Pélissier, and P. P. Mirand. 1993. Colostrum protein digestion in newborn lambs. J. Nutr. 123:586–596.