From newborn to puberty: Promoting calf immunity, development, and health through well-developed nutritional management

A.J. Fischer-Tlustos[1], MSc; **D.L. Renaud**[2], DVM, PhD; **M.A. Steele**[1], MSc, PhD
[1] University of Guelph, Department of Animal Biosciences, Guelph, ON, Canada N1G 2W1
[2] Department of Population Medicine, University of Guelph, Guelph, ON, Canada N1G 2W1
Corresponding author: Dr. M.A. Steele, masteele@uoguelph.ca

Abstract

Proper nutritional management during the first year of the calf's life is essential in maximizing health and productivity. Feeding a sufficient volume of colostrum early in life is crucial to ensure the transfer of passive immunity and research has begun to characterize the additional bioactive compounds in colostrum and transition milk that can benefit calf development. We know that it is important to feed elevated levels of whole milk or milk replacer during the initial weeks of life, when starter intake is negligible, but further research regarding the effects of feeding large volumes of traditional milk replacers compared to whole milk on calf metabolism, health and development is required. When elevated levels of milk are fed preweaning, calves are often susceptible to production challenges during weaning, which can be mitigated by weaning gradually and later in life. It is also becoming clear that postweaning diets, which are often overlooked, can have profound effects on heifer growth and reproductive development. It is clear that a multitude of differing strategies to raise dairy calves exist; yet, it is up to the dairy research and industry communities to educate producers on specific practices that will maximize heifer development, immunity, health and ultimately the profitability of their operations.

Key words: dairy heifer, colostrum, plane of nutrition, weaning

Introduction

It is becoming increasingly clear that the calf's growth and health during the pre-weaning stage can have a profound influence on her future productivity as a milking animal.[47] Thus, it is essential that we implement management practices and strategies that promote, rather than hinder, calf health and development. However, there remains a significant need to determine strategies, preferably non-antimicrobial, that reduce the high rates of morbidity (34%) and mortality (5%) in young calves.[51] There are a variety of contributors to calf illness and death, yet, digestive disorders remain the most common culprit.[51] Digestive disorders can often be prevented through the use of well-developed early life nutrition and health management programs. Amongst others, our research group has generated data from the neonatal to post-weaning stages strongly demonstrating that proper nutrition improves calf development and health, and ultimately reduces the high rates of morbidity, mortality, and antimicrobial use during early life.

Colostrum and Transition Milk Feeding

It is well-known that the calf depends on the feeding of high-quality colostrum during early life to ensure transfer of passive immunity (**TPI**). Yet, failed transfer of passive immunity (**FPTI**), defined as serum IgG < 10 mg/mL at 1 to 7 d of life,[17,50] still occurs in 12.1% of heifer calves in the US.[46] However, re-evaluating the efficacy of this traditional FPTI cut-off point has resulted in new serum IgG cut-point categories: excellent (> 25.0 g/L), good (18.0 to 24.9 g/L), fair (10.0 to 17.9 g/L) and poor (< 10.0 g/L).[34] Current FPTI rates will consequently rise to achieve a minimum of the "good" serum IgG threshold, emphasizing the need to further improve current colostrum and neonatal calf management strategies.

To ensure TPI, it is recommended that calves are fed colostrum containing ≥ 50 g of IgG/L at 10 to 12% of birth body weight (~3 to 4 L).[22] In addition, feeding colostrum immediately after birth results in greater serum IgG concentrations compared to calves fed at 6 h and 12 h of life,[13] due to intestinal epithelial cells losing the ability to absorb IgG as time after birth increases.[48] Therefore, it is commonly recommended that colostrum is fed within 4 h after birth to ensure TPI.[22] In terms of feeding method, research has largely shown that feeding ≥ 3 L of colostrum and/or colostrum replacer via nipple bottle or esophageal tube feeder does not result in any differences in serum IgG concentrations;[3,8,22] thus, either practice can be used to facilitate adequate TPI. It is important to consider that TPI may be further enhanced by feeding additional meals of colostrum after the initial 3-4 L feeding. Recently, Hare et al[25] fed calves 3-4 L of colostrum within the first 2 h of life, followed by subsequent meals of either colostrum, a 1:1 colostrum:whole milk mixture, or whole milk at 12-h intervals. Calves fed additional meals of colostrum achieved greater serum IgG concentrations (30.4

± 0.8 mg/mL) compared to calves fed whole milk (23.9 ± 0.8 mg/mL).[25] Feeding additional meals of colostrum not only improved TPI but also improved gut development, specifically by increasing small intestinal villi height and absorptive surface area (Figure 1).[43] Similar results were observed in calves fed the colostrum:whole milk mixture, demonstrating that colostrum and transition milk (**TM**) play a key role in both providing passive immunity and promoting gut development and maturation.

Nutrients within colostrum may be partially responsible for stimulating intestinal development in neonatal calves. Although protein appears to be the predominant energy source in colostrum, fat actually accounts for ~60% of digestible energy while protein only supplies ~25%. In addition to fueling the metabolism and thermoregulation of the newborn calf, high levels of fat in colostrum may induce the secretion of glucagon-like peptide (**GLP**)-2, a gut hormone that is well-known for its role in promoting gut proliferation and development. Feeding colostrum replacer stimulates large increases in plasma concentrations of GLP-2[8] and feeding colostrum immediately after birth results in greater plasma concentrations of GLP-2 compared to calves fed at 12 h after birth.[27] To corroborate the effect that GLP-2 may have on intestinal development, Fischer-Tlustos et al[15] demonstrated that delaying colostrum feeding did indeed reduce small intestinal villi height compared to feeding immediately after birth.

Colostrum also plays a vital role in the establishment of a healthy intestinal microbial community. The gut microbiome is associated with overall calf health and disease outcomes,[41] emphasizing the importance of a balanced gut microbial community on the development of the immune system and overall physiology of the host. Calves not fed colostrum have a decreased abundance of total bacteria in the small intestine at 12 h of life,[36] and withholding colostrum feeding for 12 h tends to reduce proportions of beneficial bacteria in the colon at 2 d of life.[13] Oligosaccharides, which are present at high concentrations in colostrum compared to whole milk,[16] are associated with the abundance of beneficial bacteria in the small intestine of newborn calves[14,36] and are considered to be one of the major prebiotic compounds influencing the establishment of the intestinal gut microbiome. In addition, colostrum oligosaccharides and their associated constituents may play a key role in inhibiting common intestinal pathogens[38] and enhancing the uptake of IgG into enterocytes.[12,21]

In addition to the aforementioned benefits of colostrum feeding, the first milking contains high levels of growth factors, microRNAs, hormones, cytokines and antimicrobial components that enhance the calf's ability to fight infection and promote development and growth.[2] Many of these compounds, including oligosaccharides,[16] insulin, insulin-like growth factor-1,[2] and nucleotides,[20] are also elevated in transition milk (**TM**) compared to whole milk. As previously mentioned, calves fed a colostrum:whole milk mixture (to simulate TM) have improved gut development compared to those fed whole milk (Figure 1).[43] Specifically, feeding TM promotes intestinal development to the same degree as providing solely colostrum for 3 d, despite containing less nutrients. Therefore, feeding fresh or frozen TM may be a viable and efficient strategy to improve gut development in young calves. A study conducted in Ontario, Canada demonstrated that almost 80% of producers feed TM to calves for an average of 3 d after birth[44] in order to convey enhanced health benefits. Due to the large herd sizes in the US, producers often transition calves directly to whole milk or milk replacer (**MR**) after the initial colostrum feeding; however, the exact proportion of US heifer calves fed TM is currently unknown.

Figure 1. Brightfield microscopy images *(200 x magnification) of small intestinal tissue from calves consuming either pooled colostrum, a 1:1 colostrum:whole milk mixture (COL:MILK), or whole milk feedings from 12 to 72 h of life after the initial colostrum meal within the first 2 hours of life. Data is published as Pyo et al.[43]

Plane of Milk Nutrition

Dairy calves are typically offered elevated or conventional milk feeding programs. Conventional feeding programs aim to stimulate rumen development[30] via early starter intake and limiting milk consumption to ~10% of birth body weight (**BW**; ~4-5 L of milk or 750 g of MR per day). However, calves often have reduced BW gain during the first month of life and suffer from hunger-associated behaviors, leading to both production and welfare concerns.[28] Conversely, offering elevated levels of milk (~20% birth BW, > 8 L or milk or 1.2 kg of MR per day) reduces hunger behavior, and increases BW gain, the potential to produce greater volumes of milk during future lactations, as well as improve mammary development and reproductive efficiency.[28,47,55] Despite the well-known benefits of feeding elevated levels of milk and the ability of calves to consume up to 10 L of milk/d as early as the first week of life,[24] US producers continue to feed an average of 5.7 L of milk/d during the preweaning period.[52] While this rate of milk feeding immediately prior to the weaning may be beneficial, feeding a conventional plane of nutrition during the first month of life will compromise average daily gain (**ADG**) due to negligible starter intake.[24]

Producers often assume that feeding elevated levels of milk is only feasible with the use of automated feeding technologies. However, 2-week old calves have the ability to consume 5-9 L of milk per meal without ruminal overflow[11] and can consume 4 L of milk/meal without compromising insulin sensitivity.[35] Specifically, calves offered 4 L of milk twice a day were able to slow their abomasal emptying, possibly regulating intestinal glucose delivery and the subsequent insulin response, compared to calves fed 2 L of milk 4 times per day.[35] However, it is important to note that the calves in this study[35] were fed elevated volumes of milk during the first week of life, which may be a critical developmental window in which the calf adapts to consuming high levels of milk.

Feeding Whole Milk vs Milk Replacer

Due to the aforementioned benefits of feeding large volumes of milk, the dairy industry is gradually shifting towards feeding elevated planes of whole milk or milk replacer (**MR**) during the preweaning period. Currently, 60% of US dairy operations feed solely MR or a combination of MR and whole milk.[52] Yet, further consideration of traditional MR formulations is required, as MR typically contains greater levels of lactose (40 to 50% vs 33 to 38%)[42] and lower levels of fat (16 to 22% vs 30 to 40%)[1] compared to whole milk. These differences in macronutrient composition have been hypothesized to influence calf growth and development, as well as physiology. For instance, high fat consumption is essential to meeting energy demands and assisting in thermoregulation during early life and is associated with reduced odds of mortality.[51] It is also important to note that the profile of fatty acids (**FA**) in MR differs from that of whole milk – specifically MR contains high levels of polyunsaturated FA. Feeding high levels of polyunsaturated FA can reduce nutrient digestibility and growth, as well as increase diarrhea incidence compared to feeding a MR that resembles the FA profile of whole milk.[29] Furthermore, feeding high volumes of MR containing markedly greater lactose concentrations causes concern for gut health and development. High lactose inclusion in MR increases the osmolality of MR (~400-600 mOsm/L) compared to whole milk (~300 mOsm/L), which can potentially disturb gut function in calves.[59] In addition, calves fed a high lactose MR during the first week of life experienced a greater increase in blood glucose and insulin concentrations compared to calves fed a high fat and low lactose MR.[57] In this study, calves fed the high fat MR had a reduced rate of abomasal emptying, possibly delaying the delivery of nutrients to the intestine and positively regulating glucose and insulin levels. To date, research investigating the macronutrient and fatty acid composition of MR compared to whole milk is scarce; however, it is important to determine the effects of these feeding practices on heifer physiology and the subsequent influence on development and health.

Weaning Strategies

The weaning transition is a period of drastic physical and physiological changes. Ruminal volume increases by 40%[56] and rapid maturation of the rumen transcriptome and microbiome occurs.[6,37,39] Feeding high volumes of milk or milk replacer preweaning can pose a challenge during the weaning transition, especially if weaning occurs prior to 6 weeks of age. Early weaning programs typically aim to encourage early intake of starter and rumen development; however, calves fed elevated levels of milk often consume low amounts of solid feed due to the large amount of energy supplied from milk.[28] This results in decreased digestibility of fiber, dry matter, NDF, CP, and gross energy after weaning,[9,26,49] suggesting that the gastrointestinal tract is unaccustomed to digesting solid feed during and after the weaning transition. Conversely, extending weaning age from 6 to 8 weeks of age in calves fed elevated levels of milk results in greater starter intake, weight gain, and decreased growth depression during weaning.[10,40] Implementing the "step-down" method[31,32] or weaning calves gradually using automation[58] can also improve starter intake and performance measures. Fortunately, the dairy industry has made great strides in improving the onset of weaning, with a reported average weaning age of 9 weeks in the US.[52] Yet, only 31% of calves are currently weaned based on their starter intake[52] and may be unequipped to consume and digest large amounts of starter during and after weaning.

In addition to the amount of milk fed preweaning, the impact of the amount and form of starch in calf starter on the development of the gastrointestinal tract and the outcomes of weaning requires further attention. Calves are often fed starter that is high in starch (> 30%), which can result in an accumulation of short chain fatty acids. This can lead to reduced ruminal pH and acidosis, which, if severe, can result in excessive amounts of undigested ruminal starch in the lower gut[33] and eventually in the feces.[10,54] This indicates that the lower gut may experience acidosis, which could potentially lead to the generation of a systemic inflammatory response. In addition, the form of starch, such as whole corn vs steam-flaked corn, can shift the fermentation site to the lower gut[23] and reduce fecal pH.[54] The research community has begun to recognize that significant changes occur in the lower gut during the weaning transition; yet, research investigating the interactions between high planes of milk nutrition and the form and amount of starch in starter and their effects on lower gut functional changes in the lower gut is lacking.

Post-weaning and Beyond

Calf research has primarily focused on the pre-weaning and weaning periods and the effects of common nutritional management programs during the initial months following weaning are largely uncharacterized. Although there is data to support the effects of preweaning plane of nutrition on production and health during the adult stage,[31,47] a recent study demonstrated that there was little interaction in growth and development indicators between the pre- and postweaning phases of life.[45] The prepubertal phase is a critical period in heifer development and the industry largely underfeeds heifers during the post-weaning stage. Recent work has demonstrated that improving post-weaning growth by increasing concentrate inclusion in TMR (from 70% to 85%) in post-weaning diets enhances development of the reproductive tract, the number of ovarian follicles during the first estrous cycle, and chances of achieving puberty by 30 weeks of age.[4,5] Furthermore, ADG, serum concentrations of insulin-like growth factor-1 and β-hydroxybutyrate, as well as ruminal concentrations of butyrate, were greater in heifers offered TMR with greater concentrate inclusion.[45] This indicates that heifers fed a diet high in concentrate were able to achieve increased growth and ruminal development while simultaneously improving reproductive efficiency. Furthermore, the greater body condition score (**BCS**) in heifers fed high levels of dietary concentrate suggests an increased conversion of dietary energy to fat at the expense of lean tissue growth for heifers fed greater levels of concentrate in TMR. This is often a concern during the prepubertal period during the allometric mammary growth phase[18,19] and can lead to an accumulation of fat in the mammary fat pad at the expense of parenchymal tissue growth.[7] Although positive associations were observed between greater BCS and reproductive efficiency[4,5,45] further research regarding accelerated growth rates in prepuberal heifers and mammary development and milk production is required.

Conclusion

During the pre-weaning, weaning and post-weaning phases there are a multitude of common raising strategies that hinder heifer productivity, development and health. Educating dairy producers and industry representatives on management practices that promote proper calf development is necessary to mitigate the current high rates of morbidity and mortality experienced on farm. However, research pertaining to effects that certain nutritional regimes have on specific physiological mechanisms in the calf, as well as their long-term effects on productivity and health, often requires further investigation. This information is needed to allow the dairy industry to confidently make decisions that promote calf development while ensuring health, welfare and future productivity.

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