

Dietary Effects on Ruminal Papillae During Periparturient Transition in Holstein Cows – Is Cow Performance Affected?

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The Transitioning Cow

Starting lactation drastically increases energy needs for cows. For instance, a 1500 lb dairy cow has a maintenance requirement of 10.9 MCal/day ($NE_M = 0.080 \text{ MCal/BW}^{0.75}$; NRC 2001). To produce 100 lb of milk ($NE_L = 0.749 \text{ MCal/kg}_{\text{milk}}$) a day would require an additional 33.7 MCal (NRC 2001). Meeting the energy needs of cows during this transition remains a top priority for dairy producers. The principal challenge lies in the rumen's ability to absorb volatile fatty acids (**VFA**) from the diet to meet energy demands. When the absorption of VFA falls short of energy demands, cows go into negative energy balance and require mobilization of energy reserves.

Mobilizing energy reserves, principally triglycerides to non-esterified fatty acids (**NEFA**), must occur at an appropriate pace to avoid ketosis and fatty liver disease. If cows are underconditioned at calving, triglyceride reserves are insufficient, and ketosis results. If triglyceride mobilization is too fast, NEFA will accumulate in the liver and reform triglyceride, leading to fatty liver disease. Through balanced mobilization of triglycerides, the cow can meet the energy needs of lactation without suffering metabolic diseases.

In recent decades, research on optimal triglyceride mobilization focused on nutritional management strategies, primarily in the form of manipulating mobilization of energy reserves immediately prior to calving. For example, Rastani et al. (2005) varied the length of the dry period to investigate its impact on energy balance. They tested three dry period lengths: 0, 28, and 56 days. Their most noticeable finding was that cows without a dry period experienced almost no negative energy balance (**Figure 1**). In more recent research, Gross et al. (2011) induced a negative energy balance through feed restriction to cows at 100 DIM to determine how responsive blood metabolites were to negative energy balance. The researchers found that glucose, beta-hydroxybutyric acid (**BHBA**), and NEFA changes were much lower in induced negative energy balance than they were in early lactation. Together, these studies highlight the resilience of energy homeorhesis in cows that are already lactating. When lactation is uninterrupted, cows can mobilize energy reserves much more effectively than when lactation is turned off and on.

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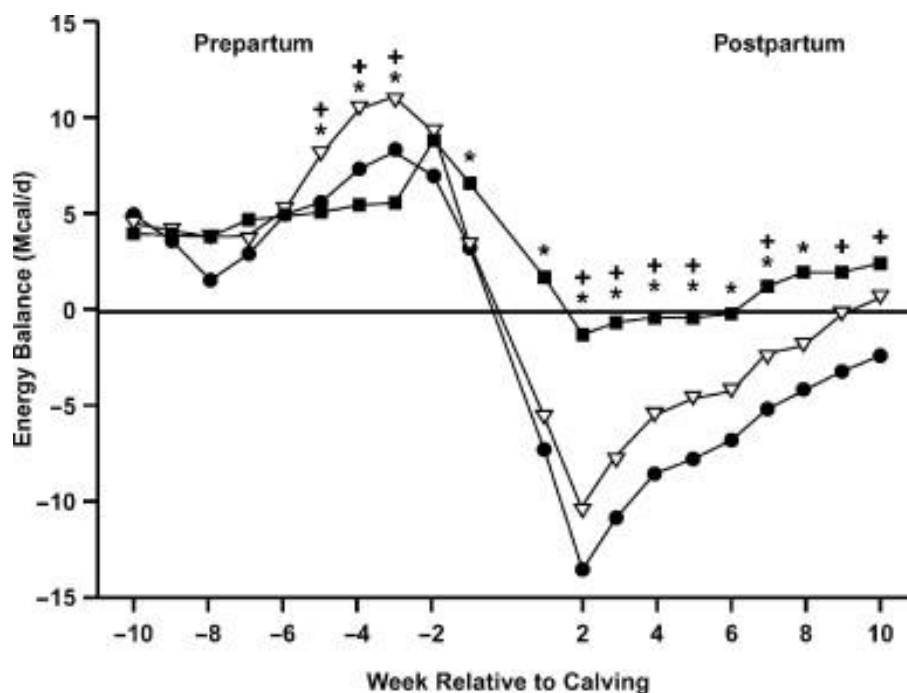


FIGURE 1. ROLE OF DRY PERIOD LENGTH ON NEGATIVE ENERGY BALANCE POST-PARTUM. A 56-DAY DRY PERIOD (CIRCLE) AND 28-DAY DRY PERIOD (TRIANGLE) CAUSED GREATER NEGATIVE ENERGY BALANCE THAN A 0-DAY DRY PERIOD (SQUARE). FROM RASTANI ET AL., 2005. ©JOURNAL OF DAIRY SCIENCE

When lactation needs to be turned on, cows need metabolic preparation to ensure a healthy transition to lactation. To facilitate preparation, cows can often be subjected to a “Goldilocks” diet, a low-energy diet fed pre-partum. Principally, low-energy diets during the dry period help mitigate postpartum negative energy balance, reduce circulating NEFA concentrations, increase plasma blood glucose, and reduce time to pregnancy (Janovick et al., 2011; Cardoso et al., 2013). While restricting energy intake pre-calving is important for performance during lactation, it sidesteps an important component of the calving transition: the adaptation of the rumen to improve VFA absorption. Increasing VFA absorption in the rumen, especially in the first weeks post-partum, holds much promise to improve negative energy balance via increasing energy intake rather than limiting energy expenditure.

The Transitioning Rumen

During the transition period, the cow may be switched from a dry period diet to a lactation diet in a matter of several days, but the rumen’s structural and cellular adaptations to the new diet takes weeks. The dietary non-fiber carbohydrate (**NFC**) content increases to as high as 45% (AlZahal et al., 2014), leading to elevated VFA production. While structural adaptations begin in the first week of the high NFC diet, the adaptation process persists to at least 6 weeks of lactation (Laarman et al., 2015, Steele et al., 2015). Until a cow fully adapts to the new diet, the need to increase energy

intake and DMI to mitigate negative energy balance elevates the risk of VFA production in the rumen exceeding VFA removal, placing considerable strain on rumen epithelial health.

The rumen epithelium carries out two important functions: absorption of nutrients from the rumen into the bloodstream and forming a barrier that prevents ruminal microbes from entering the bloodstream. Structurally, the rumen is a squamous epithelial layer consisting of four layers: the corneal layer facing the rumen, followed by the granular layer, spinous layer, and basal layer (**Figure 2**). The spinous layer contains many of the intercellular anchors and proteins that form a barrier between the rumen and the bloodstream (Graham and Simmons, 2005, Baldwin et al., 2012). While rumen pH can decrease to as low as 5.2 without clinical ruminal acidosis (Aschenbach et al., 2011), live epithelial cells in the granular, spinous, and basal layers must maintain an intracellular pH of 7.4. Facing the rumen contents, the corneal layer offers protection to the underlying layers, avoiding contact with the low pH.

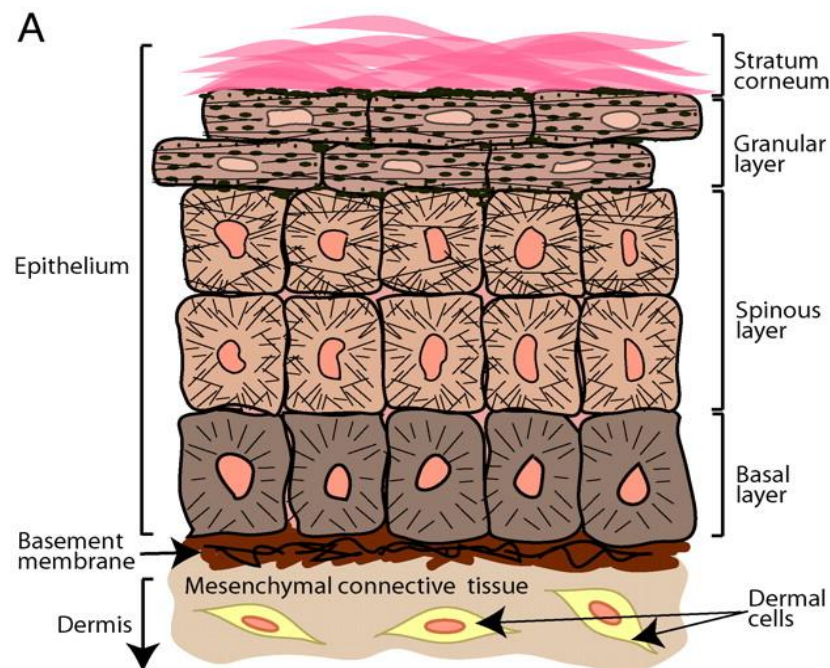


FIGURE 2. LINING THE RUMEN IS A 4-LAYER EPITHELIUM THAT PREVENTS BACTERIA FROM ENTERING THE BLOODSTREAM, LEADING TO LIVER ABSCESSSES AND LAMINITIS (ALONSO AND FUCHS, 2003; ©NATIONAL ACADEMY OF SCIENCE. USED FOR NON-COMMERCIAL PURPOSES)

Sudden transitions from a low fermentability diet to a high fermentability diet, such as those in the transition period, comprise a considerable strain on the rumen. When the rumen is insufficiently adapted to the fermentability of the diet, it cannot remove VFA and protons fast enough, resulting in subacute ruminal acidosis (**SARA**).

The impact of SARA on ruminal health is profound. The corneal layer begins to slough (Figure 3), exposing the granular and spinous layers to ruminal microbes and pH, resulting in increased permeability of the rumen epithelium (Steele et al., 2011). Indeed, in another study, low rumen pH increased permeability of the rumen epithelium to *E. coli* translocation (Emmanuel et al., 2007). Translocation of rumen microbes into the bloodstream is associated with adverse effects on animal health and productivity, including laminitis, ruminitis, and reduced milk production (Plaizier et al., 2008; Stone, 2004). Maintaining rumen pH during the transition period is of paramount importance.

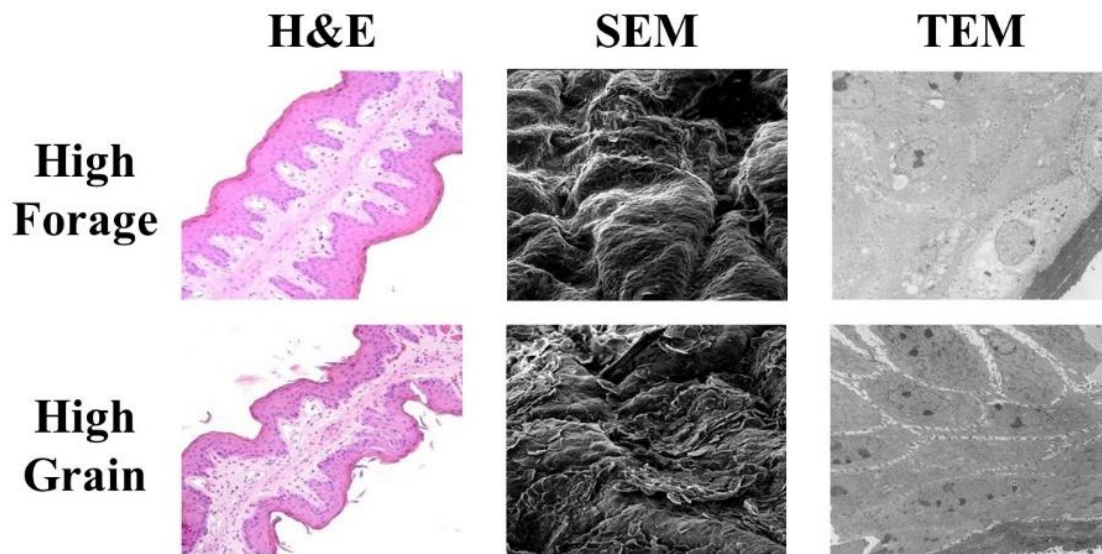


FIGURE 3. IMPACT OF SWITCHING DAIRY COWS FROM A HIGH FORAGE TO A HIGH GRAIN DIET. H&E STAIN SHOW EXTENSIVE SLOUGHING OF THE CORNEAL LAYER FACING THE RUMEN (LEFT). SCANNING ELECTRON MICROGRAPH (SEM; MIDDLE) SHOW STRIPPING OF EPIMURAL MICROBES, WHILE TRANSMISSION ELECTRON MICROGRAPH (TEM; RIGHT) DEMONSTRATE INCREASED PERMEABILITY BETWEEN EPITHELIAL CELLS. STEELE ET AL., 2011. ©ELSEVIER PUBLISHING INC.

Rumen pH dynamics are largely dependent on the adapted state of the rumen. In a study in calves, pre-weaned calves were fed either milk replacer and hay only, or milk replacer, starter, and hay (Laarman and Oba, 2011; Table 1). Calves fed starter had 50% higher VFA concentrations in the rumen, but showed no difference in rumen pH, highlighting the adaptability of the rumen. Maintaining rumen pH at physiologically healthy levels prevents adverse animal health issues such as laminitis and ruminitis (Plaizier et al., 2008). Indeed, the ability to remove VFA from the rumen is a key factor in determining resistance to SARA (Penner et al., 2009).

TABLE 1. IMPACT OF FEEDING CALF STARTER ON RUMEN FERMENTATION DYNAMICS. DESPITE HIGHER FERMENTABILITY OF THE CALF STARTER TREATMENT, AS INDICATED BY GREATER TOTAL VFA, RUMEN PH EXHIBITED NO DIFFERENCE BETWEEN TREATMENTS, DEMONSTRATING ADAPTABILITY OF RUMEN TO CHANGES IN DIET FERMENTABILITY. (LAARMAN AND OBA, 2011) ©ELSEVIER PUBLISHING INC.

	Milk & Hay	Milk & Hay & Starter
Average pH	6.42 ± 0.10	6.27 ± 0.12
Duration pH < 5.8, min/d	101 ± 100	237 ± 126
Total VFA, mM	64.6 ± 8.6	99.1 ± 8.1*
Starter DMI, kg/d	N/A	0.76 ± 0.04
Hay DMI, kg/d	0.23 ± 0.07	0.34 ± 0.8

* $P < 0.05$

The rumen's ability to absorb VFA consists of 2 major components: cellular transport (through transporters and passive diffusion) and absorptive surface area, both of which adapt to dietary changes in the short-term and long-term. In the short term, the papillae can make use of cellular transport mechanisms to improve VFA transport, using both passive diffusion and transporters in the epithelial cells to increase VFA transport (Laarman et al., 2016). In the longer-term, the transport capacity is increased by increased absorptive surface area, as demonstrated by increases in papillae length and width (Dirksen et al., 1985). Morphological changes in rumen papillae begin in the first week after calving and persist for at least 6 weeks (Laarman et al., 2015). During this adaptation, passive diffusion of VFA is responsible for most of the changes in VFA transport (Schurmann et al., 2014). In the end, the rumen papillae have changed morphologically and cellularly, with the result of improving VFA transport capacity to more closely meet the energy demands of the lactating cow.

Setting Up the Rumen for Transition Success

During the lactation transition, the energy demands of lactation and energy intake and absorption through the rumen will ultimately dictate the extent of negative energy balance. Restricting feed intake during the dry period improves the metabolic transition of dairy cows to lactation. Simultaneously, rumen papillae must increase VFA transport capacity to eventually bring the cow out of negative energy balance. As a result, priming the rumen for transition requires improvements in rumen papillae function and/or surface area without overfeeding cows. The potential to prime the rumen without overfeeding the cow mostly lies in feed additives that stimulate rumen adaptation.

One such additive is butyrate, one of the principal VFA well known for its bioactivity. In dairy cows, supplementing a highly fermentable diet (45% NFC) with butyrate at 2.5% of DMI increases VFA transport capacity and improves barrier integrity (Laarman et al., 2013a,b; Baldwin et al., 2012). When fed to prepartum Holstein cows in the last week before parturition at 300 g/day (0.66 lb/day), butyrate improved DMI by 1.7 kg/day (3.7 lb/day) (Kowalski et al., 2015). When fed to goats, butyrate increased ruminal papillae surface area (Malhi et al., 2013). The ultimate success of this supplementation strategy will ultimately be dependent on dose and timing of supplementation.

Other strategies to improve rumen adaptation to lactation diets have mixed results. Dieho et al. (2016) fed supplemental concentrate to cows in the dry period. While DMI remained similar to cows not fed supplemental concentrate, rumen papillae surface area increased. The increase in papillae surface area did not correspond to an increase in VFA transport rates, suggesting papillae surface area and VFA transport rates may behave independently. In another study focusing on cellular changes in the transition period from 3 weeks prepartum to 9 weeks post-partum, cows exhibited morphological changes in rumen papillae but no differences in VFA transport capacity (Laarman et al., 2015).

Together, these strategies aim to capitalize on the adaptability of the rumen to prepare it for the energy demands of early lactation. Successful adaptation of the rumen requires nutritional strategies that stimulate papillae adaptation without providing excess energy to the cow. Within that targeted window lie opportunities to improve the VFA absorption capacity of cows as they enter lactation. The more VFA absorption capacity is improved at calving, the more energy can be taken in by the cow, and the more diminished the negative energy balance will be. Diminishing negative energy balance will ultimately improve cow productivity and health, and the rumen can play an important role in accomplishing that goal.

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SESSION NOTES