

Managing Energy Metabolism in Transition Dairy Cows

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Management to support the metabolic adaptations related to energy metabolism that a dairy cow undergoes during the transition period and early lactation is a critical factor in transition period success. Energy balance is tightly linked with reproductive performance (Butler and Smith, 1989), aspects of health and immunity (LeBlanc, 2010), and markers of excessive negative energy balance are generally negatively associated with milk yield (Ospina et al., 2010). Although a common notion is that milk yield is the major driver of negative energy balance, several data summaries (Santos et al., 2009; reviewed by Grummer et al., 2010) suggest that the relationship of negative energy balance is actually greater with dry matter intake (DMI) than with milk yield. Therefore, the major determinant of successful management of energy metabolism in transition cows may be the degree and rate to which energy intake increases during the early postpartum period.

Clearly, nutritional and environmental management of dairy cattle during the dry and transition period have important carryover ramifications both for DMI and overall lactational and reproductive performance along with health in early lactation. The purpose of this paper is to briefly overview intake regulation in dairy cattle, describe key metabolic changes in transition cows as they integrate with intake regulation and then to review key nutritional factors during both the prepartum and postpartum period that impact peripartum DMI and energy metabolism so that we can optimize energy and nutrient intake and subsequent performance and health outcomes.

INTAKE REGULATION IN DAIRY CATTLE

The first key concept to understand is that intake regulation in dairy cattle is complex. The various metabolic factors that influence DMI in dairy cattle were well-reviewed by Ingvarstsen and Andersen (2000) and includes a variety of direct and indirect signals related to the environment, immune system, adipose tissue, signals from the gut and pancreas, and energy sensing of the liver relative to overall energy demand (Figure 1). It is likely that changes in these signals (and cow-to-cow variation in response to various environmental and metabolic stimuli) are responsible both for changes in overall average pen DMI but also variation in cow to cow DMI that likely is more associated with transition management challenges than average pen DMI per se.

More recently, Allen and coworkers (Allen et al., 2005; Allen et al., 2009) proposed that a major regulator of DMI in ruminants, and particularly dairy cattle, was hepatic energy status. This is largely driven by oxidation of fuels such as propionate derived from ruminal fermentation of rapidly fermentable carbohydrates and nonesterified fatty acids (NEFA), which are increased in the bloodstream during periods of negative energy balance and body fat mobilization (Figure 2). In periods when oxidative fuel metabolism by the liver exceeds liver energy requirements, the brain is signaled to decrease DMI. As will be discussed more in detail below, this theory is particularly attractive in explaining metabolic influences on DMI during the prepartum period. As will be described below, modulation of these pathways, particularly by propionate is less likely during the immediate postpartum period because of the large increases in liver energy demands along with other reasons that will be discussed below.

METABOLIC ADAPTATIONS IN THE TRANSITION COW

It is well-recognized that the dairy cows undergo important metabolic adaptations during late pregnancy to support fetal demands and at the onset of lactation to support milk production. These homeostatic adaptations involved in the regulation of nutrient and energy partitioning during late pregnancy and early lactation occur in a variety of target tissues, and typically involve changes in responses of tissues such as adipose tissue and muscle to homeostatic signals such as insulin and epinephrine (Bauman and Currie, 1980; Bell, 1995). As described above, one major adaptation includes a large increase in glucose demand by the mammary gland that is supported by dramatically increased glucose output by the liver (Reynolds et al., 2003). In addition, peripheral tissues (primarily skeletal muscle) decrease their use of glucose for fuel (Bauman and Elliot, 1983; Petterson et al., 1993), thereby sparing glucose for use by the gravid uterus and lactating mammary gland. Furthermore, increased mobilization of body fat stores facilitated by changes in adipose tissue metabolism contributes to meeting increased whole-body needs for energy at the onset of lactation (Petterson et al., 1994). The net result of these adaptations is coordinated support of fetal needs and subsequent high milk production in the face of decreasing and eventually insufficient DMI during late pregnancy and early lactation.

These changes in tissue metabolism that occur in dairy cows during the transition period are mediated largely by changes in responses to hormonal signals such as insulin. Decreased responses of these tissues to insulin are referred to in general terms as insulin resistance. As referenced above, some aspects of insulin resistance (such as those related to skeletal muscle) are very favorable for support of pregnancy and lactation because of glucose sparing for the fetus and lactating mammary gland (Bell, 1995). At the same time, we believe that insulin resistance in adipose tissue may contribute to the increasing circulating concentrations of NEFA and decreasing DMI as cows approach calving. Allen et al. (2005) suggested that the increased circulating concentrations of NEFA during late pregnancy and subsequent oxidation of these NEFA by the liver is the cause of the decreased DMI as cows approach calving. Increased resistance of adipose tissue to insulin would predispose to the cow to mobilize NEFA, hence potentially creating a vicious cycle of NEFA mobilization and DMI reduction during the late prepartum period. This would also help to explain metabolically why high body condition score (BCS) cows have lower DMI and more rapid decreases in DMI during the prepartum period than cows of moderate or low BCS (Grummer et al., 2004).

Several years ago, we became interested in further understanding the nature and timing of insulin resistance, with specific focus on determining whether the relationships of NEFA and DMI could be modulated during the transition period. Initial research conducted in our lab (Smith, 2004) suggested that adipose tissue in periparturient dairy cows actually may be more refractory to insulin during the prepartum period than during the postpartum period. Subsequent work also generally supported the concept that insulin resistance may be greater during the prepartum period than the postpartum period (Smith et al., 2006).

As a result of this work and other circumstantial evidence that accentuated insulin resistance during the prepartum period contributes to lower periparturient DMI, elevated NEFA concentrations, and increased body condition score (BCS) loss during early lactation, we wanted to determine whether specific modulation of insulin resistance in adipose tissue during the prepartum period would decrease NEFA mobilization and change the patterns of DMI and NEFA during the transition period. Using an experimental approach, we administered compounds (thiazolidinediones; TZD) analogous to those used to treat Type II diabetes in humans to dairy cows during the prepartum period. In the first study, TZD administration tended to decrease circulating concentrations of NEFA and tended to increase DMI during the period from 7 days before calving until 7 days after calving (Smith et al., 2007). Importantly, TZD administration did not appear to

interfere with the glucose sparing by peripheral tissues that is important for support of pregnancy and lactation.

In a second study (Smith et al., 2009) conducted using larger numbers of cows, we replicated the results of the first experiment in that TZD administration during the prepartum period decreased circulating NEFA concentrations and increased DMI during the immediate pre- and postpartum periods. In addition, TZD administration improved postpartum energy balance, decreased BCS loss, and decreased days to first ovulation in treated cows. These results suggested that specific modulation of insulin resistance in adipose tissue could have very positive effects on metabolic changes during the transition period and have substantial carryover effects on the dynamics of metabolism and performance during early lactation. It should be noted that this work was conducted as proof of concept relative to the mechanisms of metabolic regulation; TZD currently is not available in a form that can be used practically in the dairy industry and would require regulatory approval before such use.

PREPARTUM NUTRITIONAL MANAGEMENT AND RELATIONSHIPS WITH PERIPARTAL DRY MATTER INTAKE

Although modulation of insulin resistance using pharmaceutical approaches is intriguing, it causes us to ask questions regarding which aspects of nutritional management may influence insulin resistance. During the past few years, energy nutrition of cows during the dry period has received substantial renewed attention (Drackley and Janovick-Guretzky, 2007) and an increasing body of information suggests that energy nutrition may interact with insulin resistance during the late prepartum period.

For many years, the emphasis of researchers and industry professionals was to maximize DMI in order to ensure that cows consumed enough energy during the dry period. This strategy was supported in part by research that demonstrated that cows with lower NEFA concentrations during the last two weeks before calving on commercial dairy farms had decreased incidence of most postcalving metabolic disorders (displaced abomasum, ketosis, retained placenta, mastitis; Dyk, 1995). Given that higher DMI typically results in lower circulating NEFA, the association between higher DMI and improved health and performance was implied. Our experience would suggest that many farms indeed had improved health and performance when management changes were implemented that increased DMI of cows, particularly during the close-up period.

On the other hand, evidence suggests that plane of nutrition, in particular energy intake during the prepartum period, modulates the degree of insulin resistance and hence the relationships between NEFA

and DMI during the immediate periparturient period. Mashek and Grummer (2003) reported that cows that had larger decreases in DMI during the prepartum period, generally because of higher DMI during weeks 3 and 4 before calving, had higher concentrations of plasma NEFA and liver triglycerides during the postpartum period. More direct experimental evidence was provided by Douglas et al. (2006), who reported that cows fed at 80% of calculated energy requirements for the entire dry period had lower NEFA concentrations during the postpartum period, lower concentrations of both circulating glucose and insulin during the prepartum period, and higher DMI during the postpartum period than cows consuming 160% of predicted energy requirements throughout the dry period. Similarly, Holcomb et al. (2001) reported that cows subjected to feed restriction during the late prepartum period had blunted NEFA curves during the periparturient period. In addition, Holtenius et al. (2003) determined that cows that were dramatically overfed (178% of calculated energy requirements) for the last 8 weeks before calving had higher concentrations of insulin and glucose during the prepartum period, greater insulin responses to glucose challenge during the prepartum period, and higher concentrations of circulating NEFA during the postpartum period than cows fed for 75 or 110% of calculated energy requirements. Furthermore, Agenas et al. (2003) reported that the same cows fed for 178% of calculated energy requirements prepartum had lower DMI and prolonged negative energy balance during the postpartum period compared with cows assigned to the other two prepartum treatments. Dann et al. (2006) demonstrated that overfeeding (150% of calculated energy requirements) during the far-off period may have exacerbated insulin resistance as cows approached calving, resulting in higher NEFA and BHBA and lower DMI and energy balance during the first 10 days postcalving.

Recently, we compared responses to insulin through glucose tolerance tests conducted on dry cows fed a high energy, corn silage-based (~ 0.69 Mcal/lb of NEL; 170% of predicted energy requirements) ration versus a high straw, bulky diet (~ 0.61 Mcal/lb of NEL; 119% of predicted energy requirements; Schoenberg and Overton, 2012). Responses of NEFA to the glucose tolerance test were more refractory in the cows fed the high energy diet, suggesting that feeding the high energy diet to dry cows accentuated the insulin resistance expressed in adipose tissue. Collectively, these results support that overfeeding energy to dry cows results in changes in metabolism that in turn likely predispose cows to decreased DMI and higher NEFA during the immediate periparturient period.

This knowledge has supported the evolution in recommendations for energy nutrition of dairy cows during both the far-off and close-up periods during the past several years, with the goal of meeting, but not

dramatically exceeding, energy requirements. My target range for both the far-off and close-up periods is between 110 and 120% of energy requirements. In practice, this can be achieved by formulating diets during the far-off period to contain no more than 0.59 to 0.63 Mcal/lb of NEL in order to achieve the target NEL intake of approximately 15 to 17 Mcal for Holsteins during this timeframe. During the close-up period, conventional recommendations as described above have been to maximize DMI, and hence energy intake. Although this still applies in many herd situations, we believe that some well-managed herds in which close-up cows consume large amounts of feed (> 31 to 32 lbs/day of dry matter in commingled cow/springing heifer groups) have increased rates of metabolic disorders because of excessive energy intake during the close-up period. Accordingly, some of these herds have had success in moderating energy intake during the close-up period in group-feeding situations by incorporating straw or other low potassium, low energy forage to lower overall dietary energy concentration. Our recommendations would be to formulate the close-up diet at approximately 0.64 to 0.66 Mcal/lb of NEL if the group is a commingled cow/heifer group and approximately 0.61 to 0.63 Mcal/lb of NEL if the group is composed of mature animals and DMI is high. This lower energy diet also can be an acceptable one-group dry cow approach if overall herd management dictates such an approach. Diets formulated in these ranges will help to ensure adequate, but not excessive energy intake within the dynamics of group-feeding and competition among animals.

Diets formulated using a combination of corn silage and straw to form the forage component of the diet typically can have between 5 to 10 lbs of chopped straw, making feeding management a critical component of implementation of bulky, low energy dry cow diets. As described by Drackley (2007), the three key components of this implementation are 1) prevention of sorting, 2) ensuring continuous and non-crowded access to the TMR, and 3) careful monitoring of dry matter content and attention to detail. Most of these diets will contain added water in order to aid with prevention of sorting. A final point relative to these types of diets is that it is important to account for the metabolizable protein requirements of the cow during late pregnancy. These diets typically contain lower amounts of ruminally fermentable carbohydrate than those that have been typically fed for the last ten to fifteen years, and therefore will supply less metabolizable protein from ruminal bacteria. Inclusion of rumen-undegradable protein sources to result in total metabolizable protein supply in the range of 1,100 to 1,200 g/d is critical for early lactation performance and overall success. Furthermore, in anecdotal cases where these diets have been linked with lower milk yield during early lactation, I speculate that energy intake may have been pushed too low, especially during the close-up period.

POSTPARTUM NUTRITIONAL MANAGEMENT AND RELATIONSHIPS WITH DRY MATTER INTAKE AND METABOLISM IN EARLY LACTATION

As is described in another paper in the proceedings (Dann and Nelson, 2011), the amount of research specifically conducted to explore the relationships of postpartum nutritional management and the dynamics of DMI and BCS during early lactation has been very limited. Allen et al. (2009) would suggest that feeding highly fermentable diets to cows during early lactation would decrease DMI and overall energy status. I contend that modulation of DMI by propionate during very early lactation is less likely than at other phases of lactation for several reasons. First, NEFA likely are the predominant oxidative fuel for liver during this period and so any hypophagic effect of propionate would depend upon NEFA supply to the liver. Second, we demonstrated that there is a positive correlation between liver capacity to convert propionate to glucose and fat free NEL intake (proxy for carbohydrate intake) in cows at d 1 and 21 postcalving that does not exist either before calving or at peak lactation (Drackley et al., 2001). This suggests that the liver has the capacity to direct additional propionate toward glucose. Third, hepatic energy requirements increase dramatically at the onset of lactation (Reynolds et al., 2003). The first point is supported by recent work (Stocks and Allen, 2011), in which they determined that the hypophagic effects of propionate increased when hepatic acetyl CoA concentrations are higher, as they would be if cows were mobilizing large amounts of adipose tissue with the corresponding proportionate uptake of NEFA by the liver.

The limited work in fresh cows (with the exception of the results from Dann and Nelson, 2011) suggests that feeding more fermentable diets during early lactation does not decrease DMI or negatively impact other aspects of performance and metabolic health.

Andersen et al. (2002; 2003) fed cows either a low (25% concentrate) or high (75% concentrate) diet with whole crop barley silage as the forage base from calving through 8 wk postcalving. Feeding the high energy diet did not affect DMI, increased net energy intake and milk yield, and did not affect BCS change in early lactation. Cows fed the high energy diet had greater liver capacity to convert fatty acids to CO₂, lower capacity to convert fatty acids to triglycerides in liver, and lower blood ketones (Andersen et al., 2002).

Rabelo et al. (2003; 2005) fed cows and first calf heifers either low or high energy diets prepartum followed by either low or high energy diets postpartum until d 20 postcalving, then all cows were fed the high energy diet through d 70 postcalving. The postcalving diets were based upon alfalfa silage and corn silage – the “low” energy diet contained 29.9% NDF and 41.4% NFC; the

“high” energy diet contained 24.9% NDF and 47.2% NFC. Cows fed the high energy diet postpartum tended to have higher DMI and had higher energy intake from d 1 to 30; overall effects of treatment from d 1 to 70 postcalving were not significant. Rates of increase of milk production were greater for cows fed high energy diets postcalving, and plasma concentrations of BHBA were substantially lower for cows fed the high energy diet on d 7 and 21 postcalving.

Although these studies (Andersen et al., 2002; Rabelo et al., 2003) suggest that higher energy diets are preferable during the postcalving period, the diets fed by Andersen represent the extremes and those fed by Rabelo are both higher energy diets by industry standards. This area certainly warrants active investigation.

SUMMARY AND CONCLUSIONS

Success in management of energy metabolism during the transition period depends upon excellent management in a number of different areas to manage the dynamics of DMI and body condition mobilization along with optimize performance. Our understanding of the metabolic regulation underpinning the changes that occur in energy metabolism of cows during the transition period is increasing, and with this understanding has come new potential opportunities for enhancing transition cow health and performance. Controlling energy intake of cows during the prepartum period (both far-off and close-up) is an important factor that predisposes cows to smoother adaptations to lactation. Furthermore, available information suggests that feeding higher energy diets (or not feeding a diet lower in energy than the high cow diet) promotes higher energy intake and milk yield along with better metabolic status during the postpartum period.

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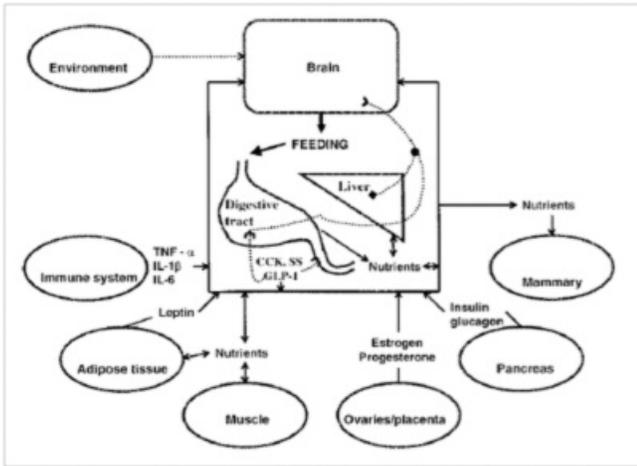


Figure 1. “Simplified” diagram on intake regulation in dairy cattle. From Ingvarsten and Andersen, 2000.

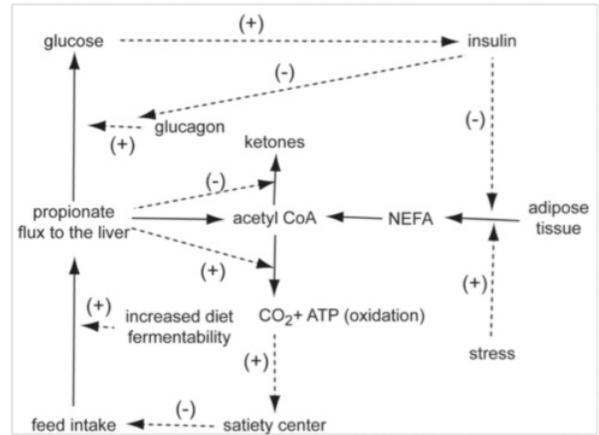


Figure 2. Mechanisms of intake regulation according to the hepatic oxidation theory. From Allen et al., 2009.

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