The Effects of Dry Period Versus Continuous Lactation on Metabolic Status and Performance in Periparturient Cows

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ABSTRACT

It has been argued that dairy cows with a high genetic milk production potential can maintain high milk production even with total omission of the dry period. Further, when omitting the dry period, cows are believed to experience fewer metabolic changes during the transition from late gestation to early lactation compared with cows having a traditional dry period. The performance and metabolic response to omission of the dry period for cows with an expected peak milk yield higher than 45 kg/d were studied in 28 Holstein dairy cows. The cows were followed in late gestation and in the subsequent 5 wk of early lactation. Fourteen cows were milked through late gestation (CM) and another 14 dairy cows underwent a 7-wk dry period (DRY). In the early lactation period, the cows had the same dry matter (DM) intake but cows in the CM group had a 22% reduction in milk yield compared with the cows in the DRY group. At calving, the experimental groups had the same average body weight and body condition score and there were no significant differences in body weight and body condition score changes in early lactation. However, the cows in the CM group compared with the cows in the DRY group had a higher plasma concentration of glucose and insulin and a lower plasma concentration of nonesterified fatty acids and \( \beta \)-hydroxybutyrate in the following 5 wk of early lactation. Furthermore, the cows in the CM group had lower liver triacylglycerol concentration and higher liver glycogen concentration in the following early lactation. It is concluded that, even in dairy cows with an expected peak milk yield above 45 kg/d, omission of the dry period results in a relatively high reduction in milk yield in the following early lactation. Furthermore, these cows are in less metabolic imbalance in the following early lactation.

 INTRODUCTION

The high-yielding dairy cow experiences massive metabolic changes during the transition from the dry period in late gestation to the onset of copious milk secretion in early lactation (Bell, 1995; Ingvartsen and Andersen, 2000). During this period the cow has to adapt to a dramatic and several-fold increase in nutrient uptake by the mammary gland associated with lactogenesis compared with the much smaller nutrient requirement in late gestation by the growing conceptus. The periparturient period is thus associated with an increased incidence of metabolic and production-related diseases, including fatty liver and ketosis, arising because of inadequate homeorhetic adaptation of metabolism (Ingvartsen and Andersen, 2000; Ingvartsen et al., 2003; Friggens et al., 2004).

The 6- to 8-wk dry period is included in the traditional dairy management between successive lactations to ensure optimal milk production in the following lactation (Swanson, 1965; Sørensen and Enevoldsen, 1991; Remond et al., 1997a,b). Indeed, several studies have demonstrated that total omission of the dry period (i.e., continuous lactation) decreases milk production in the following lactation by 20 to 40% (Sanders, 1928; Swanson, 1965; Smith et al., 1967; Remond et al., 1997a,b). However, the level of milk production in these studies has been relatively low—between 20 and 30 kg/d at peak lactation. In a French study from the mid-1990s, it was reported that continuous lactation had been practiced successfully for 15 yr in a commercial dairy herd with a production level >10,000 kg of energy-corrected milk (ECM) (Remond and Bonnefoy, 1997). A recent study by Annen et al. (2004a) further demonstrated that continuous lactation had no negative influence on...
milk production in the subsequent lactation in bST-treated multiparous dairy cows with a production level >12,000 kg of ECM, whereas primiparous cows had lower production postpartum. These results could be explained by the bST treatment because somatotropin and IGF-I in the bovine seem to be some of the most important hormones controlling the processes involved in mammary redevelopment in the dry period including cell death (apoptosis) and proliferation (Accorsi et al., 2002). Genetic selection for milk yield has resulted in dairy cows with an inherent, higher endogenous somatotropin secretion (Kazmer et al., 1986). It is therefore tempting to hypothesize that, even in cows not treated with bST, it may be possible to maintain very high milk production under continuous lactation management, provided the cows are of a high genetic merit and kept in a herd with a high standard of management.

Another interesting observation in the French study was that, when omitting the dry period, the cows had an atypically low mobilization of BW in the following early lactation, suggesting lesser negative energy balance in early lactation (Remond and Bonnefoy, 1997). An explanation of this could be that the continuously lactating cow experiences less dramatic metabolic changes during the transition from late gestation to early lactation due to: 1) achievement of higher peak feed intakes in the following early lactation and at a faster rate as a result of a more functional rumen; or 2) depression of milk production in the following lactation due to impaired mammary redevelopment prepartum.

The objective of this study was to evaluate if omission of the dry period for high-yielding, nonbST-treated dairy cows can 1) be practiced without significant negative influence on milk yield in the following lactation; and 2) reduce the metabolic imbalance associated with the onset of lactation.

Changes in a variety of blood metabolites, hormones, liver triacylglycerol (TAG), and glycogen contents were followed as indicators of metabolic status and adaptive changes in the periparturient period (Andersen et al., 2002, 2004).

**MATERIALS AND METHODS**

**Experimental Animals and Design**

A homogeneous group of 28 Danish Holstein dairy cows (11 in first lactation; 17 in ≥second lactation) were selected from among the cows with the highest merit for milk yield and a good health record (i.e., treatment frequency and days open in previous lactation) in the dairy herd of the Danish Institute of Agricultural Sciences, Research Center Foulum (Tjele, Denmark).

Seven weeks before expected calving date, the cows were blocked according to genetic merit of milk yield, lactation number, and BW after calving in the first lactation and randomly allocated to 1 of 2 experimental groups. The cows in the control group (DRY, 5 in first lactation; 9 in ≥second lactation) were dried off 7 wk before expected calving. The cows in the continuous lactation group (CM, 6 in first lactation; 8 in ≥second lactation) were milked until parturition unless the daily milk yield declined to less than 5 kg/d.

All cows were fed the same TMR twice a day at 0800 and 1400 h and had free access to water. The TMR was a mixture of corn silage (33.3%), grass silage (20.9%), rolled barley (10.1%), grass pellets, dried (13%), rapeseed cake (17.6%), sugar beet molasses (4.6%), and feed urea (0.5%). From 7 to 3 wk before expected calving, the cows in group DRY were fed restrictedly (9 kg of DM of the TMR) and barley straw ad libitum, according to Danish norms for dry cows (Strudsholm et al., 1999). Until calving and in the following lactation, these cows were fed TMR ad libitum. The cows in the CM group were fed TMR ad libitum throughout the experiment. Further, all cows received a daily supplement of mineral, salt, and vitamin mixture to fulfill the requirements of the Danish norms (Strudsholm et al., 1999). A daily feed refusal of 5% or more was the aim for TMR fed ad libitum. All daily milkings were performed at 0430 and 1530 h. The cows were kept in a tie-stall barn and bedded with barley straw twice daily. The experimental period was from 7 wk before expected calving to 6 wk after the actual calving date.

The experimental procedures were conducted under the protocols approved by the Danish Animal Experiments Inspectorate and complied with the Danish Ministry of Justice Law no. 382 (June 10, 1987) and Acts 739 (December 6, 1988) and 333 (May 19, 1990) concerning animal experimentation and care of experimental animals.

Two cows from the DRY group were excluded due to amputation of teats in connection with mastitis just after calving. Another 2 cows in the CM group dried themselves off in connection with mastitis approximately 2 wk prepartum. These cows were excluded from the experiment. In total, 7 of the cows in the CM group were dried off between 7 and 2 d prepartum due to a milk yield of less than 5 kg/d, given an average dry period length for these cows of 4 ± 4 d. The average dry period length of the cows in the DRY group was 47 ± 5 d.

**Registration and Sampling**

Feed intake was recorded daily and feed was sampled as described by Ingvartsen et al. (2001). All cows were weighed 7 wk prepartum (time of drying-off for DRY cows) and subsequently every week on a fixed day and...

Table 1. The chemical composition and calculated energy contents of the diet.

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>% of DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude fat</td>
<td>4.8</td>
</tr>
<tr>
<td>NDF</td>
<td>34.3</td>
</tr>
<tr>
<td>Sugar</td>
<td>7.4</td>
</tr>
<tr>
<td>Starch</td>
<td>16.1</td>
</tr>
<tr>
<td>CP</td>
<td>16.1</td>
</tr>
<tr>
<td>Net energy, SFU/kg of DM</td>
<td>0.91</td>
</tr>
</tbody>
</table>

1One Scandinavian Feed Unit (SFU) = 7890 KJ of net energy/kg of DM (Strudsholm et al., 1997).

...time until the end of the experiment. Body condition score was determined weekly on a fixed day of the week using a scale from 1 to 5, including half points, where 1 = thin and 5 = obese (Kristensen, 1986). Milk yield was recorded weekly. At the day of milk yield recording, proportional milk samples were obtained from each milking and stored at 5°C until analysis. Blood samples were obtained from a jugular vein approximately 5 h after the morning feeding on Wednesdays from wk 5 before to wk 6 after calving. Blood was sampled in Vacutainer tubes (Becton Dickinson Vacutainer Systems, Plymouth, UK) containing sodium heparin as an anticoagulant. Within 30 min of collection, the blood samples were centrifuged at 2000 × g for 4°C for 20 min, and the plasma was collected and frozen at −20°C until further analysis.

Liver biopsies were taken in wk −3, 1, and 5 around calving. Liver biopsies (6 × 20 mg biopsies) were obtained through an incision on the right side of the cow at the 10th intercostal where it crossed a line from midhumerus to tuber coxae. Before taking the biopsies, a 5 × 5 cm area was shaved and disinfected, and a 5-mL local anesthesia (Hostacain Vet, 2%; Intervet, Skovlund, Denmark) was given. After a minimum of 10 min, a 0.5-cm incision in the skin was made. Liver biopsies were taken from this incision using a Manan Automatic Biopsy System (14 gauge × 17 mm notch) (Marmom/MDTech, Gainesville, FL). The biopsies were immediately frozen in liquid nitrogen and transported to the laboratory where the biopsies were stored at −80°C until analyzed.

Analysis

Feed samples were analyzed as described by Ingvartsen et al. (2001), and the average chemical composition of the TMR mix is presented in Table 1. Milk was analyzed for fat, protein, lactose, and cell content using a MilkoScan FT 120 (Foss Electric A/S, Hillerød, Denmark). Blood plasma samples were analyzed for NEFA, glucose, BHBA, plasma urea nitrogen (PUN), calcium, insulin, and bST. Analytical procedures for BHBA and NEFA were adapted and performed using an autoanalyzer, OpeRA Chemistry Systems (Bayer Corporation, Tarrytown, NY). Glucose, PUN, and calcium were determined according to procedures by Technicon RA Systems (Methods Manual, publ. no. TH9-1589-01, May 1994, Bayer Corp.) using an autoanalyzer. Blood analyses were described in detail by Mashek et al. (2001). Plasma concentrations of bST and insulin were determined using noncompetitive time-resolved immunofluorometric assay (sandwich type). The time-resolved fluorescence from europium was read following chelation with an enhancement solution (Wallac, Oy, Finland). These analyses were described in detail by Mashek et al. (2001).

Two liver biopsies (approximately 40 mg wet weight) were weighed directly from −80°C into 2.0 mL of ice-cold PBS and kept on ice until homogenization for 30 s with an ultrasound sonicator (High Intensity Ultrasonic Processor, VC130; Sonics and Materials, Inc., Newton, CT). The homogenate was centrifuged at 2000 × g for 10 min at 4°C. A representative sample of the supernatant was analyzed for glycogen. The glycogen analysis was based on an enzymatic colorimetric commercial kit modified to fit small tissue samples and performed on an autoanalyzer (OpeRA Chemistry System, Bayer Corp.) as described by Andersen et al. (2002). Liver TAG content was determined after a lipid extraction that was performed on approximately 40 mg of tissue and 6 mL ice-cold hexane/isopropanol solution, and homogenized for 15 s with the ultrasound sonicator. The lipid was extracted in the solution for a minimum of 12 h and centrifuged at 800 × g for 5 min. Two milliliters of aqueous Na2SO4 was poured into the solution and vigorously mixed before centrifugation at 800 × g for 5 min. The hexane layer was removed to a new tube and evaporated in a vacuum centrifuge at 30°C and 400 × g. The extracted lipid was dissolved in 1 mL of isopropanol at 40°C and shaken for 3 h. The TAG analysis was based on an enzymatic colorimetric commercial kit modified to fit small tissue samples and performed on an autoanalyzer (OpeRA Chemistry System, Bayer Corp.).

Calculations

Based on the daily feed intakes, an average daily feed intake was calculated on a weekly basis. The milk composition and milk yield were used to calculate ECM as described by Sjaunja et al. (1990). Responses in BW and BCS in early lactation were calculated as the differences between BW and BCS at calving and wk 5 of lactation.
Statistical Analyses

Milk samples were not taken from a significant number of cows during the week of parturition (wk 0); data for milk composition in this week have therefore not been included in the statistical analyses. The effects of experimental treatments were analyzed in 2 separate periods—before and after calving. The treatment and week effects on performance, plasma, and liver parameters were analyzed using the REML method of the procedure MIXED (SAS Institute, 1996). The model contained fixed effects of treatments and weeks, and random effect of cow within treatment. For the repeated measurements, the model also contained weeks from calving and the interaction between treatments and weeks from calving. Initially, a treatment × parity interaction was included in the model, but due to nonsignificant results this was excluded in the final model; for example, P-values for the effect of treatment × parity interaction were 0.31 and 0.36 for milk (kg/d) and ECM (kg/d), respectively. To adjust for differences in length of the dry period, we calculated, within each treatment group, the differences between the actual length of the dry period and the average length of the dry period and included these as covariates in the model. Variables with a single observation per cow, such as mobilization parameters, were analyzed with the omission of repeated measures, “weeks”, and interactions including “weeks” in the model. The covariance structure of repeated measurements yielding the best fit according to Akaike’s information criterion or Schwarz’ Bayesian criterion was chosen. The variance was homogeneous across individual weeks. The option SLICE under the LSMEANS procedure was used to test effects in situations where interactions were significant. To obtain normal distribution of residuals, the plasma concentrations of NEFA, BHBA, insulin, and bST were log-transformed and these variables are reported as the geometric least squares means, but with the standard errors of the log-transformed means. All values are reported as least squares means and standard error of means.

RESULTS

Feed Intake, Milk Production, and Milk Composition

The effects of treatment on DMI, milk production, and milk composition are shown in Table 2 and Figures 1 and 2. In the late pregnancy period (wk −5 to 0), the average DMI were higher in the CM group (P < 0.0001). A significant interaction between treatment and weeks from calving (P < 0.0001) showed that cows in the DRY group increased their DMI from wk −5 to 0 (9.8 to 15.1 ± 1.0 kg), whereas the cows in group CM had a decrease in DMI from wk −5 to 0 (20.0 to 16.4 ± 1.0 kg), resulting in similar feed intakes at parturition in the 2 groups. It is important to remember that the DMI was restricted until wk −3 for cows in the DRY group. In the following early lactation period, the DMI increased in both groups (P < 0.0001) from calving until the end of the experiment and no significant (P = 0.29) differences were observed in DMI between the 2 groups.

In late pregnancy, milk production was declining (P < 0.0001) each week for the cows in the CM group. Further, from wk 5 to 0 prepartum, the weekly fat, protein, and cell contents of the milk were increased (P < 0.0001) and the weekly lactose content of the milk was decreased (P < 0.0001). In the following early lactation period, cows in the CM group had an approximately 22% lower milk yield (P < 0.0006) compared with cows in the DRY group. The average milk yield (ECM) was 44.6 and 35.9 kg/d (SE = 1.1 kg/d) for the DRY and CM treatments, respectively. The protein percentage was significantly (P = 0.0002) highest for cows in the CM group. The average protein percentage was 3.25 and 3.62 (SE = 0.04%) for the DRY and CM treatments, respectively. Except for the protein percentage, there were no differences (P > 0.19) in milk composition in the following early lactation.

BW and BCS

The BW and BCS data are presented in Table 3 and Figure 2. The average BW and BCS were 675 ± 23 kg and 3.7 ± 0.1, respectively, in wk −5, 654 ± 19 kg and 3.7 ± 0.1 in wk 1, and 631 ± 18 kg and 3.3 ± 0.1 in wk 5. Body weight and BCS increased slightly in the weeks precalving (P < 0.01) followed by a more dominant decrease in BW and BCS in the weeks postcalving (P < 0.001). The BW and BCS were not at any time different between treatments, and neither were the changes between treatments in BW and BCS from calving to wk 5 from calving (P > 0.34).

Plasma Metabolites and Hormones in Late Pregnancy

Plasma metabolite and hormone data are presented in Table 4 and Figure 3. Plasma glucose concentrations were significantly higher (P = 0.03) during late pregnancy in cows in the CM group, and a significant (P = 0.03) week × treatment interaction showed that this was due to a more rapid increase in the plasma glucose concentration from wk −4 to calving than was seen in cows in the DRY group. The plasma NEFA concentration decreased (P < 0.0006) during late pregnancy for both treatments until 2 wk before calving, when the concentration started to increase rapidly. The average
Table 2. The effect of management with or without a dry period in late pregnancy (DRY and CM, respectively) on feed intake and milk production during the periods 5 to 0 wk before and 1 to 5 wk after parturition.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Time, wk†</th>
<th>Experimental group</th>
<th>SE</th>
<th>P-value</th>
<th>T × Wk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DRY</td>
<td>CM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>−5 to 0</td>
<td>13.0</td>
<td>18.3</td>
<td>2.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>1 to 5</td>
<td>22.7</td>
<td>21.5</td>
<td>1.6</td>
<td>0.27</td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td>−5 to 0</td>
<td>12.5</td>
<td>12.5</td>
<td>3.2</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>1 to 5</td>
<td>12.5</td>
<td>12.5</td>
<td>3.2</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>ECM,4 kg/d</td>
<td>−5 to 0</td>
<td>40.9</td>
<td>32.1</td>
<td>3.4</td>
<td>0.0003</td>
</tr>
<tr>
<td></td>
<td>1 to 5</td>
<td>44.6</td>
<td>35.9</td>
<td>4.0</td>
<td>0.0006</td>
</tr>
<tr>
<td>Fat, %</td>
<td>−5 to 0</td>
<td>4.33</td>
<td>4.32</td>
<td>0.46</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>1 to 5</td>
<td>5.0</td>
<td>5.0</td>
<td>0.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Protein, %</td>
<td>−5 to 0</td>
<td>3.25</td>
<td>3.25</td>
<td>0.13</td>
<td>0.0002</td>
</tr>
<tr>
<td></td>
<td>1 to 5</td>
<td>4.7</td>
<td>4.7</td>
<td>0.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Lactose, %</td>
<td>−5 to 0</td>
<td>4.81</td>
<td>4.88</td>
<td>0.11</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>1 to 5</td>
<td>625</td>
<td>625</td>
<td>772</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SCC, ×1000</td>
<td>−5 to 0</td>
<td>288</td>
<td>246</td>
<td>424</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>1 to 5</td>
<td>772</td>
<td>625</td>
<td>882</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

†Wk = Week relative to calving.
‡SE = Standard error of the model.
§T = Treatment in dry period.

plasma NEFA concentration was highest \((P = 0.05)\) for the cows in the DRY group. A significant \((P = 0.002)\) week × treatment interaction showed that the plasma concentration of BHBA increased for treatment DRY from wk −5 to wk −2 followed by a slight decrease until calving, whereas BHBA for cows on treatment CM decreased from wk −5 until calving to reach levels at parturition similar to those of cows on the DRY treatment. Plasma urea nitrogen levels were not different between treatment groups during the last weeks of pregnancy. However, a significant \((P = 0.02)\) week × treatment interaction showed that cows in group DRY had an increased PUN concentration from wk −5 to wk −3, whereas cows in the CM group had only minor changes in PUN concentration in late pregnancy. Until the last week before calving, both treatments showed relatively constant plasma Ca concentration followed by a more rapid decrease in the last week before calving \((P = 0.01)\). On average, the plasma insulin concentration was highest \((P = 0.04)\) in the last 3 wk compared with wk 5 and wk 4 before calving and there were no differences between treatments in late pregnancy. Bovine somatotropin levels were not affected by either week or treatment in late pregnancy.

**Plasma Metabolites and Hormones in Early Lactation**

The plasma glucose concentration decreased from the week of calving to wk 1 after calving followed by a slight increase from wk 3 to wk 5 after calving \((P = 0.001)\). The average glucose concentration was highest \((P = 0.003)\) for cows on the CM treatment. In early lactation, the NEFA concentration was highest \((P < 0.0001)\) in the week of calving and the first week after calving for treatments DRY and CM, respectively. Thereafter, the NEFA concentration decreased until wk 2, with no further significant changes during the last part of the experiment. The average NEFA concentration was highest \((P = 0.02)\) for cows in the DRY group. Plasma BHBA had a tendency \((P = 0.07)\) to increase from the week of calving to the first week after calving with no further changes over the experimental period. On average, the BHBA concentration was highest \((P = 0.04)\) for cows in the DRY group in early lactation. Plasma urea nitrogen was not affected by week or experimental treatment in early lactation. There were no overall effects of experimental treatment on the plasma level of calcium \((P = 0.44)\), but calcium increased \((P = 0.0003)\) during the first week of the early lactation with no further changes in the experimental period. The plasma insulin concentration had its nadir \((P = 0.002)\) in wk 1 after calving and increased slightly during early lactation. On average, the plasma insulin concentration was substantially higher \((P = 0.004)\) for the cows in the CM group (44.9 pmol) after calving than in the DRY group (28.0 pmol).

The highest plasma ST levels were found in the week of calving in both groups. A tendency \((P = 0.06)\) to an interaction between treatment and weeks after calving showed that cows in the DRY group had the highest plasma ST concentration in the first 3 wk after calving with no differences after this period.

**Liver TAG and Glycogen**

Liver TAG and glycogen data are presented in Table 4 and Figure 4. Neither the liver TAG nor glycogen
METABOLIC STATUS AND OMISSION OF THE DRY PERIOD

Figure 1. Changes in milk yield, milk fat content, milk protein content, milk lactose content, and milk SCC (ECM = energy-corrected milk). Twenty-eight dairy cows (11 in first lactation; 17 in ≥second lactation) were followed during the period between 5 wk before and 5 wk after parturition by weekly samplings. Treatments were: omission of the dry period (CM: ▌) or 7-wk dry period (DRY: ○). See Table 2 for statistical tests.

concentration was significantly different between treatments in late pregnancy (wk −3). On average, the TAG concentration was highest ($P = 0.0008$) and glycogen was lowest ($P = 0.0005$) in wk 1 compared with wk 5. Cows in the CM group had, in wk 1 and wk 5, the lowest ($P = 0.01$) TAG concentration and highest ($P = 0.04$) glycogen concentration compared with cows in the DRY group. However, a tendency ($P = 0.07$) toward an interaction between week and treatment showed that the difference in TAG concentration was most pronounced in wk 1 compared with wk 5 after calving.

DISCUSSION

The milk yield in the present experiment, both in late lactation and in the subsequent early lactation, was significantly higher than in previously reported studies concerning continuous lactation in cows not treated with bST (Sanders, 1928; Swanson, 1965; Smith et al., 1967; Remond et al., 1992, 1997a). Moreover, the milk yield is comparable with that of a high-producing commercial dairy herd in France, where management without dry period has been used successfully for at least 15 yr (Remond and Bonnefoy, 1997). Therefore, the present experiment contributes new information to the impact of continuous lactation throughout gestation in high-yielding dairy cows on both milk production as well as metabolic adaptation to the following lactation.

Fourteen cows were originally assigned to the CM treatment. The level of milk production in these cows 7 wk prepartum was quite high (>25 kg of ECM/d), but in spite of this, only 5 cows managed to remain lactating.
Figure 2. Changes in DMI, BW, and BCS. Twenty-eight dairy cows (11 in first lactation; 17 in ≥ second lactation) were followed during the period between 5 wk before and 5 wk after parturition by weekly samplings. Treatments were: omission of the dry period (CM: ■) or 7-wk dry period (DRY: ◆). See Table 2 for statistical tests on DMI. Body weight and BCS were affected by weeks from calving (P < 0.01). See Table 3 for statistical tests on BW and BCS.

throughout the gestational period. Two cows dried themselves off spontaneously due to mastitis approximately 2 wk prepartum (excluded from the experiment) and the milking of 7 cows was stopped between 2 and 7 d prepartum when their milk production decreased below 5 kg of ECM/d. That some cows dry themselves off spontaneously a few weeks before calving, even with high milk yield capacity, has been reported in previous studies (e.g., Remond et al., 1997a; Annen et al., 2004a). Besides treatment of mastitis, we were not able to identify any specific parameters indicative of whether a cow would have the potential to accomplish a full continuous lactation or not.

Recent data indicate that omission of the dry period has a more profound effect on milk yield in primiparous than in multiparous bST-treated cows (Annen et al., 2004a). However, the present experiment does not provide sufficient statistical power to evaluate possible differences between parities in nonbST-treated dairy cows.

Effect of Continuous Lactation vs. Drying-Off on Milk Production and Composition During Transition

The decrease in milk yield, dramatic increase in milk fat, milk protein content, and SCC, and decrease in milk lactose during late pregnancy found in the present experiment are in agreement with observations in earlier studies. Remond et al. (1992) and Annen et al. (2004b) contain excellent discussions on this matter, and it will consequently not be discussed further in this paper.

The milk yield in early lactation was 8.8 kg/d lower for group CM compared with group DRY, and the relative decrease in the present study was of the same magnitude (22%) although the production in the control group peaked at a much higher level (>45 kg of ECM/d) compared with earlier studies (Swanson, 1965; Smith et al., 1967; Remond et al., 1992). Our study does therefore not support the suggestion put forward by Remond and Bonnely (1997) that omission of a dry period has less influence on milk production in the following early lactation of dairy cows with a high genetic merit compared with low-yielding cows. On the contrary, the nonlactating period in late pregnancy appears to be equally important in dairy cows of high genetic merit for obtaining maximum milk production potential in the following early lactation. As discussed later, cows in the CM group had a similar DMI and improved metabolic balance in early lactation. It seems logical to suggest that the lower milk yield in these cows is a consequence of unfortunate events during redevelopment of the mammary gland in late gestation (e.g., Capuco et al., 1997; Annen et al., 2004b) rather than a consequence of shortage of nutrients to sustain milk synthesis. The lower capacity for milk production in the subsequent lactation in the CM cows must therefore be attributable to some form of disturbance in the local regulation of mammary cell proliferation and differentiation, although the nature of this disturbance is presently unknown.

Cows in the CM group had a higher milk protein content in early lactation, which agrees with the findings of Farries and Hoheisel (1989) and Remond et al.
Table 3. The effect of management with or without a dry period in late pregnancy (DRY and CM, respectively) on BW and BCS at wk −5, 1, and 5 after parturition.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Time, wk</th>
<th>Experimental group</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DRY</td>
<td>CM</td>
</tr>
<tr>
<td>BW</td>
<td>−5</td>
<td>670</td>
<td>679</td>
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<tr>
<td></td>
<td>1</td>
<td>661</td>
<td>646</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>634</td>
<td>628</td>
</tr>
<tr>
<td>BW change</td>
<td>1 to 5</td>
<td>26.3</td>
<td>18.0</td>
</tr>
<tr>
<td>BCS</td>
<td>−5</td>
<td>3.8</td>
<td>3.6</td>
</tr>
<tr>
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<td>1</td>
<td>3.7</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>3.2</td>
<td>3.4</td>
</tr>
<tr>
<td>BCS change</td>
<td>1 to 5</td>
<td>0.5</td>
<td>0.4</td>
</tr>
</tbody>
</table>

¹Wk = Week relative to calving.
²SE = Standard error of the model.
³T = Treatment in dry period.

(1997b) in continuously milked cows in late gestation. An explanation could be better energy balance in the continuously milked cows because an improvement in energy status generally has a positive effect on the protein content of milk (Remond et al., 1992). However, the increase in milk protein content could not compensate for the depression in overall milk yield, and the daily milk protein yield was negatively affected by the CM treatment as well.

Table 4. The effect of management with or without a dry period in late pregnancy (DRY and CM, respectively) on plasma and liver parameters during the periods 5 to 0 wk before and 1 to 5 wk after parturition.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Time, wk ¹</th>
<th>Experimental group</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DRY</td>
<td>CM</td>
</tr>
<tr>
<td>Plasma</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Glucose, mmol/L</td>
<td>−5 to 0</td>
<td>3.42</td>
<td>3.67</td>
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<td>1 to 5</td>
<td>3.22</td>
<td>3.54</td>
</tr>
<tr>
<td>NEFA, ² mEq/L</td>
<td>−5 to 0</td>
<td>0.19</td>
<td>0.16</td>
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<tr>
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<td>1 to 5</td>
<td>0.25</td>
<td>0.19</td>
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<tr>
<td>BHBA, ³ mmol/L</td>
<td>−5 to 0</td>
<td>0.60</td>
<td>0.73</td>
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<tr>
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<td>1 to 5</td>
<td>0.96</td>
<td>0.73</td>
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<tr>
<td>Plasma urea N, mmol/L</td>
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<td>4.58</td>
<td>4.84</td>
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<td>1 to 5</td>
<td>3.93</td>
<td>4.11</td>
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<tr>
<td>Calcium, mmol/L</td>
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<td>2.59</td>
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<tr>
<td></td>
<td>1 to 5</td>
<td>2.55</td>
<td>2.52</td>
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<tr>
<td>Insulin, ⁴ pmol/L</td>
<td>−5 to 0</td>
<td>72.2</td>
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<td>1 to 5</td>
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<td>bST, ⁵ ng/mL</td>
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<td>0.69</td>
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<td>1 to 5</td>
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<td>0.97</td>
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<td>Liver</td>
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<td>4.35</td>
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<td>1 and 5</td>
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<td>10.32</td>
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<tr>
<td>Glycogen, mmol/g</td>
<td>−3</td>
<td>227</td>
<td>243</td>
</tr>
<tr>
<td></td>
<td>1 and 5</td>
<td>169</td>
<td>210</td>
</tr>
</tbody>
</table>

¹Wk = Week relative to calving.
²SE = Standard error of the model.
³T = Treatment in dry period.
⁴Geometric mean of log-transformed data.
⁵SE based on log-transformed data.

Effect of Continuous Lactation vs. Drying-Off on DMI During Transition

The decrease in DMI in late pregnancy for cows on the CM treatment is consistent with the drop in milk yield, and the relative decrease in DMI is consistent with the traditional dip in DMI for dry cows fed ad libitum in late pregnancy (Hayirli et al., 2002; Andersen et al., 2003). The cows in group DRY were fed restrict-
Figure 3. Changes in plasma concentrations of glucose, plasma urea N (PUN), NEFA, BHBA, Ca, insulin, and hST. Twenty-eight dairy cows (11 in first lactation; 17 in second lactation) were followed during the period between 5 wk before and 5 wk after parturition by weekly samplings. Treatments were: omission of the dry period (CM: ■) or 7-wk dry period (DRY: ◇). See Table 4 for statistical tests.
Changes in liver triacylglycerol (TAG) and glycogen contents. Twenty-eight dairy cows (11 in first lactation; 17 in ≥ second lactation) were followed in wk −3, 1, and 5 around parturition. Treatments were: omission of the dry period (CM: ■) or 7-wk dry period (DRY: □). See Table 4 for statistical tests.

Effect of Continuous Lactation vs. Drying-Off on Metabolic Imbalance During Transition

In late pregnancy, the general pattern was that plasma NEFA concentrations decreased, whereas both plasma glucose and insulin concentrations increased from wk −5 to wk −2. These changes correlated with the increase in DMI for cows in the DRY group and a relatively faster decrease in milk production relative to the decrease in DMI in the CM group during the same period. The increase in plasma concentrations of NEFA and glucose in the last 2 wk before calving in the present experiment is normally observed in dairy cows at this stage (Andersen et al., 2004) and is related to metabolic adaptations around calving (Ingvartsen and Andersen, 2000). The CM cows had significantly higher plasma concentrations of glucose and BHBA and a lower NEFA concentration in late pregnancy than DRY cows, which may be explained by the ad libitum feeding giving rise to higher nutrient absorption, including BHBA.

In early lactation, both plasma glucose and insulin concentrations were significantly higher in CM cows, which also tended to have the lowest plasma bST concentrations in the first 3 wk after calving. This provides evidence that the CM cows were experiencing less metabolic imbalance in early lactation. Further, the higher NEFA concentration in the DRY cows suggests that there was a greater mobilization of body fat in these cows because the higher NEFA concentration reflects a higher rate of lipolysis in the adipose tissue (Mashek et al., 2001). The NEFA are potential substrates for ketogenesis in the liver (Heitmann and Fernandez, 1986) explaining why cows in the DRY group had higher plasma BHBA concentration. β-Hydroxybutyrate contribution from gut absorption would be expected to be similar in the 2 groups in early lactation due to the lack of difference in DMI.

Liver TAG content is a function of plasma NEFA concentration and the capacity of the liver to perform long-chain fatty acid oxidation (Emery et al., 1992). The lower plasma NEFA concentration in early lactation in CM cows is a plausible explanation of the lower liver TAG content. However, a higher capacity for hepatic long-chain fatty acid oxidation is also possible due to the fact that the increase in liver TAG content in the periparturient period in the CM group was significantly lower than normally observed in studies investigating traditional dry cow management (Grummer, 1993; Grum et al., 1996; Andersen et al., 2002). A too-high liver TAG content in early lactation is associated with a range of metabolic and infectious diseases, and in determining the exact level of DMI on a given diet (Friggens, 2003).
many cases, a high TAG infiltration in the liver precedes the occurrence of other clinical diseases (Herdt, 1992).

Body weight and BCS were not affected by treatment in early lactation despite the more favorable relationship between feed intake and nutrient output in milk in the CM group. This may, however, not be so surprising as it can be calculated (NRC, 2001) that the total difference between experimental groups in energy output in ECM in the early lactation period would result in a total difference of less than 0.5 BCS units. This value is within the measurement error for BCS. However, the evidence on differences in metabolic status coming from plasma metabolite and liver TAG infiltration data throw doubt on the value of BW and BCS data as tools to evaluate metabolic imbalance in early lactation.

The more favorable metabolic state in the CM cows obviously arises from a more favorable relationship between nutrient provision and nutrient output in milk due to a lower capacity for milk production. This, on the other hand, confirms that lower milk yield in continuously lactating cows is not a consequence of lack of available nutrients coming to the udder (Pitkow et al., 1972; Knight and Wilde, 1987; Capuco and Akers, 1999; Annen et al., 2004b).

CONCLUSIONS

Omission of the dry period for dairy cows with an expected peak milk yield higher than 45 kg/d resulted in significantly lower milk yield in the following early lactation without affecting the DMI. Milk yield in the prepartum period was therefore not a major determinant of DMI. Cows managed without the dry period experienced less severe metabolic imbalance in early lactation due to the more favorable relationship between nutrient intake and nutrient output in milk.

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