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Herd-level association of serum metabolites in the transition period with disease, milk production, and early lactation reproductive performance

N. Chapinal,*†[1] S. J. LeBlanc,* M. E. Carson,* K. E. Leslie,* S. Godden,‡ M. Capel,§ J. E. P. Santos,# M. W. Overton,‖ and T. F. Duffield*
*Department of Population Medicine, University of Guelph, Ontario, Canada, N1G 2W1
†Animal Welfare Program, University of British Columbia, BC, Canada, V6T 1Z4
‡Department of Veterinary Population Medicine, University of Minnesota, St. Paul 55108
§Perry Veterinary Clinic, Perry, NY 14530
#Department of Animal Science, University of Florida, Gainesville 32611
‖Department of Population Health, University of Georgia, Athens 30602

ABSTRACT

The objective was to identify herd-level indicators expressed as a proportion of sampled animals with increased nonesterified fatty acids (NEFA) or β-hydroxybutyric acid (BHBA), or decreased calcium in wk −1 and wk +1 relative to calving that were associated with herd-level incidence of retained placenta, metritis and displaced abomasum, milk production, and probability of pregnancy at the first artificial insemination (AI). Fifty-five Holstein freestall dairy herds in the United States and Canada were visited weekly. Blood was collected from 2,365 cows around parturition, and serum concentrations of NEFA, BHBA, and calcium were determined. Different cow-level metabolite thresholds associated with detrimental health or productivity in previous studies were used to classify animals into high- and low-risk metabolite concentration groups. For wk −1 and wk +1 relative to calving, a herd-level threshold was determined as the proportion of sampled animals in the high-risk metabolite concentration groups with the strongest association with increased incidence of disease, milk loss, or decreased pregnancy at the first AI. The odds of displaced abomasum after calving were higher in herds that had ≥25% of the animals with BHBA ≥1,400 μmol/L in wk +1 [odds ratio (OR) = 2.1; 95% confidence interval (CI) = 1.0–4.2)] or ≥35% of the animals with calcium ≤2.1 mmol/L in wk +1 (OR = 2.4; CI = 1.3–4.3). Herd-level thresholds of ≥15% of the cows with BHBA ≥800 μmol/L in wk −1 and ≥15% of the cows with calcium ≤2.1 mmol/L in wk +1 were associated with milk loss (±SE) of 4.4 ± 1.7 and 3.8 ± 1.4 kg/d per cow, respectively. When only multiparous cows were considered, herds with ≥30% of the multiparous cows with NEFA ≥0.5 mEq/L in wk −1 were associated with a 3.0 ± 1.5 kg/d per cow milk loss. The odds of pregnancy at first AI were lower in herds that had ≥5% of the cows with calcium ≤2.1 mmol/L in wk −1 (OR = 0.7; CI = 0.5–1.0), or ≥30% of the cows with NEFA ≥1.0 mEq/L (OR = 0.6; CI = 0.4–0.9) or ≥25% of the cows with calcium ≤2.1 mmol/L in wk +1 (OR = 0.7; CI = 0.5–0.9). When only multiparous cows were considered, the odds of pregnancy at first AI were lower in herds that had ≥50% of multiparous cows with NEFA ≥0.5 mEq/L in wk −1 (OR = 0.5; CI = 0.2–0.9). In conclusion, several herd-level thresholds for the proportion of cows with increased NEFA or BHBA, or decreased calcium in the week before and after calving were associated with higher risk of displaced abomasum, milk loss at the first Dairy Herd Improvement Association test, and decreased pregnancy at first AI. The association found between precalving BHBA and milk production is promising due to the availability of several cow-side tests for measuring BHBA. Some of the herd-level associations differed from the previously described cow-level associations, suggesting the potential of interpreting periparturient metabolic challenges at the herd level, where changes in diet and management are generally implemented.
Key words: negative energy balance, nonesterified fatty acid, β-hydroxybutyric acid, hypocalcemia

INTRODUCTION

Maintaining health and productivity in the transition period is one of the most difficult challenges that dairy herds face. Dry matter intake decreases around parturition, whereas energy and calcium demands for lactation increase. This results in negative energy balance (**NEB**) with subsequent increased lipid mobilization and production of ketone bodies (Herdt, 2000). Moderate to substantial hypocalcemia also occurs in the first few days after calving (Goff, 2008; Reinhardt

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[1]Corresponding author: nchapinal@yahoo.com

et. al., 2011). Measures of peripartum concentrations of circulating NEFA, BHBA, and calcium are useful indicators of the ability of the cows to cope with metabolic challenges in the transition period. Serum concentrations of NEFA and BHBA measure mobilization and oxidation of fat, respectively, and reflect the success of a cow in adapting to NEB (Herdt, 2000). Serum calcium concentrations reflect the ability of a cow to replace extracellular calcium lost to milk production by withdrawing calcium from bone and by increasing the efficiency with which dietary calcium is absorbed (Horst et al., 1994).

At the cow level, increased serum concentrations of NEFA and BHBA, and decreased concentrations of calcium around parturition have been associated with increased risk of disease (Ospina et al., 2010a; Chapinal et al., 2011; Seifi et al., 2011), milk loss (Duffield et al., 2009; Ospina et al., 2010b; Chapinal et al., 2012), and impaired early reproduction (Walsh et al., 2007; Ospina et al., 2010b). Recently, cow-level thresholds of these metabolites have been determined to identify individuals at risk of impaired health or productivity (Ospina et al., 2010 a,b; Chapinal et al., 2011, 2012). However, individual cow interventions to minimize undesirable effects of NEB and hypocalcemia are often labor intensive (e.g., drenching with propylene glycol or calcium supplements). Most health-promotion strategies including nutrition and other aspects of management are logically and practically implemented at the herd level.

Ospina et al. (2010c) followed 2 separate cohorts of cows (before and after calving) in herds in the northeastern United States. Herd-level alarms for pre- and postcalving NEFA and postcalving BHBA were determined (i.e., proportion of sampled animals with concentrations of NEFA and BHBA above thresholds associated at the cow level with undesirable outcomes) to be associated with increased herd-level incidence of displaced abomasum and clinical ketosis, decreased pregnancy rate and milk production loss. The objective of the current study was to identify herd-level indicators expressed as proportion of sampled animals with increased NEFA or BHBA or decreased calcium in wk −1 and wk +1 relative to calving that were associated with herd-level changes in the incidence of retained placenta, metritis and displaced abomasum, milk production at the first DHIA test, and probability of pregnancy at the first AI. To our knowledge, this is the first study to determine herd-level thresholds for peripartum calcium and precalving BHBA. It uses a representative sample from most of the major dairy regions of the United States and Canada and, in contrast to Ospina et al. (2010c), it follows the same cohort of animals through the peripartum period.

MATERIALS AND METHODS

Data Collection

Fifty-five Holstein freestall dairy herds located across the United States and Canada were selected based on the herd managers' willingness to participate in the study; further details of the study sample can be found in Chapinal et al. (2011) and Chapinal et al. (2012). Study herds were required to be subscribed to a milk recording service (DHIA) and to have a minimum of 100 milking cows (range: 100 to 6,000 cows). Herds were recruited in 4 regions: Midwest (Minnesota and Wisconsin), Northeast (New York and Ontario), Southeast (Florida, Georgia, North Carolina, South Carolina, and Virginia), and West (California). The target sample per herd was 30 cows, based on 95% confidence of detection of a 10% outcome prevalence in a herd of 1,000, requiring 29 animals (Dohoo et al., 2009). The median number of cows and heifers sampled per herd was 36 (range = 21 to 91). On average, 27% of the cows sampled were heifers. However, in 1 herd, all of the cows sampled were primiparous and in 4 herds, all of the cows sampled were multiparous. The median number of multiparous cows sampled was 27 (range = 0 to 91).

Technicians visited each herd weekly, at the same time on the same day of the week. Animals were enrolled beginning 10 d before expected calving date using lists generated from herd management software programs (Dairy Comp 305, Valley Agricultural Software, Tulare, CA, or PCDART, Dairy Records Management Systems, Raleigh, NC). A 10-mL blood sample was collected from the coccygeal vessels into an evacuated sterile tube without anticoagulant (Vacutainer; Becton-Dixon, Franklin Lakes, NJ) at enrollment. Subsequent samplings occurred until calving (so that each animal had a sample within the week before calving) and in wk 1, 2, and 3 after calving. The samples were kept chilled and allowed to clot. Blood was centrifuged and the serum was separated and stored at −20°C within 8 h of collection. Herd managers recorded disease events with a standard form. Technicians educated herd managers through the use of verbal discussion and information sheets on case definitions of disease events to standardize the information collected. The definitions of disease events are described in LeBlanc et al. (2002).

Serum was sent to the Animal Health Laboratory, University of Guelph, for analyses of NEFA, BHBA, and total calcium concentrations. All biochemical tests were conducted on an automated analyzer (Hitachi 911 Analyzer; Randox, Laval, Quebec, Canada), using reagents supplied by Randox. Serum that was sent to

Guelph from distant regions was packed in coolers to maintain −20°C and shipped by overnight courier.

Dairy Herd Improvement test-day milk production data and pregnancy at the first AI were retrieved from herds using on-farm Dairy Comp 305 or PCDART software and assembled in an Access database (Microsoft Corp., Redmond, WA).

Data Analysis

Statistical analyses were performed with SAS (version 9.2; SAS Institute Inc., Cary, NC) considering the herd as the experimental unit. The 5 outcomes of interest were proportion of sampled animals with retained placenta, metritis, or displaced abomasum within the first 30 DIM, average milk production at the first DHIA test of the sample animals (because cow-level associations between peripartum metabolite concentrations and milk loss were stronger when using the first test only; Chapinal et al., 2012), and proportion of sampled animals diagnosed pregnant to the first AI.

Only metabolite concentrations from samples taken in wk −1 and +1 relative to calving were used for the herd-level analysis because these times were when most of the cow-level associations with disease, milk production, and pregnancy at first AI were found (Chapinal et al., 2011, 2012). To maintain temporal associations between metabolite concentrations and the outcome variables, only blood samples that were taken before the disease occurred or before the first DHIA test were considered in the respective analyses. Therefore, only samples taken in wk −1 were considered for the analysis when retained placenta and metritis were the outcome variables. For each metabolite and week of sampling, 2 cow-level thresholds based on prior analyses of these data (Chapinal et al., 2011, 2012) for the prediction of disease, milk loss, and pregnancy at the first AI were used one at a time to categorize cows into high- and low-risk groups. For wk −1, the cow-level thresholds considered were NEFA $\geq$0.3 and $\geq$0.5 mEq/L, BHBA $\geq$600 and $\geq$800 μmol/L, and calcium $\leq$2.1 and $\leq$2.3 mmol/L. For wk +1, the thresholds considered were NEFA $\geq$0.5 and $\geq$0.7 mEq/L, BHBA $\geq$900 and $\geq$1,400 μmol/L, and calcium $\leq$2.1 and $\leq$2.2 mmol/L. The proportions of sampled animals in the high-risk metabolite concentration groups, based on each cow-level threshold, were calculated for each herd. For each week of sampling and for each metabolite threshold, a series of herd-level thresholds with 5 percentage point increments of the proportion of animals in the high-risk metabolite concentration group (e.g., $\geq$10% of cows with precalving NEFA $\geq$0.3 mEq/L, $\geq$15% of cows with precalving NEFA $\geq$0.3 mEq/L, $\geq$20% of cows with precalving NEFA $\geq$0.3 mEq/L, and so on) was created to be tested for associations with herd-level outcomes. Hierarchical dummy variables were created for the different herd-level thresholds, designating a value of 1 for the herds considered at high risk (proportion of animals in the high-risk metabolite concentration group at or above threshold) and a value of 0 otherwise (e.g., herds with $\geq$10% of cows with precalving NEFA $\geq$0.3 mEq/L were assigned a value of 1 for that particular threshold, and herds with <10% of the cows with precalving NEFA $\geq$0.3 mEq/L were assigned a value of 0). Only thresholds with at least 10% of herds in a possible increased-risk category were considered further.

Differences in the outcome variables between the high- and low-risk herds were tested using general linear models (PROC GLM; SAS Institute Inc.). The proportions of the sampled animals diagnosed with disease and pregnant at first AI are continuous variables, but they can only have a value between 0 and 1. If a linear model is applied directly to proportions, the estimate of the means and confidence intervals could fall outside this range. To ensure that estimates and confidence intervals were correctly calculated, a logit transformation with a bias correction factor of 0.25 or 0.5 (Cox and Snell, 1970) was applied to the proportion of the sampled animals diagnosed with disease and pregnant at first AI. This transformation was also necessary to meet the assumptions of normality and homogeneity of variance. Separate multivariable models were created for each week of sampling and cow-level metabolite threshold, including the dichotomized proportion of animals in the high-risk metabolite concentration group (1 herd-level threshold coded as a dummy variable at a time), the proportion of primiparous cows sampled in the herd, region and herd size, and the biologically plausible 2-way interactions. Variables and interactions were removed from the final model if $P > 0.05$ by manual backward elimination. From each model, the herd-level threshold having a positive β coefficient on the logit scale in the case of diseases, and a negative β coefficient in the case of milk production and pregnancy at the first AI (on the logit scale for the latter), and the lowest *P*-value were chosen as the optimal herd-level threshold for predicting disease, milk loss, and impaired early lactation reproduction. Where more than 1 herd-level threshold was associated with the same outcome and week of sampling, the herd-level threshold based on the highest cow-level (concentration) threshold in the case of NEFA and BHBA, and the lowest cow-level threshold in the case of calcium was reported as the optimal herd-level threshold. Similar models, but without including the proportion of primiparous cows sampled were run including only multiparous cows, because some of the associations found at the cow level between metabolite concentrations and the outcome variables were only

Table 1. Herd-level associations of increased metabolite concentrations in wk +1 relative to calving with displaced abomasum, controlling for region (n = 55 herds)

Metabolite	Herd-level threshold[1] (%)	Farms above threshold (%)	OR[2]	CI	*P*-value
All cows					
BHBA[3] ≥1,400 μmol/L	≥25	15	2.1	1.0–4.2	0.04
Calcium ≤2.1 mmol/L	≥35	24	2.4	1.3–4.3	0.003
Multiparous cows only					
BHBA[3] ≥1,400 μmol/L	≥25	21	1.8	1.0–3.3	0.04
Calcium ≤2.1 mmol/L	≥30	43	1.9	1.2–3.0	0.004

[1]Expressed as percentage of sampled cows in the high-risk metabolite concentration group.

[2]Odds ratio; odds of displaced abomasum in a high-risk herd (above the herd-level threshold) compared with a low-risk herd (below the herd-level threshold).

[3]Serum BHBA.

significant for multiparous cows (Chapinal et al., 2011, 2012). One herd had only primiparous cows sampled; therefore, it was not included when multiparous cows only were considered. Results were very similar when this herd was either included or excluded in the analyses considering both multiparous and primiparous cows; therefore, it was retained in the whole-herd analyses. Residuals were examined after each model to verify normality and homogeneity of variances as well as to detect possible outliers and influential observations. In the case of disease and pregnancy at first AI, where a logit transformation was applied, coefficients were back-transformed and results are presented as odds ratios and confidence intervals between herds above and below the herd-level threshold. The odds ratio expresses how much higher the odds of experiencing an event (i.e., displaced abomasum or pregnancy) are for a high-risk herd (above the herd-level threshold) as compared with a low-risk herd (below the herd-level threshold). Milk production results are presented as the difference in mean milk production (kg/d) ± standard error between herds above and below the herd-level threshold.

RESULTS

From the 55 herds studied, 2,365 cows were sampled across the 4 study regions between May 2006 and January 2007 and used in the disease analysis. Only data from 45 herds and 1,919 cows were used in the milk production analysis, as a result of missing values for some cows and 10 herds lacking routine monthly DHIA milk production-recording data. Data on pregnancy at first AI were available for 48 herds and 2,069 cows.

Disease

The median proportion (and interquartile range) of animals with disease were 0.06 (0.03, 0.10) for retained placenta, 0.07 (0, 0.19) for metritis, and 0.03 (0, 0.7) for displaced abomasum. Eleven, 15, and 19 herds out of the 55 herds sampled had no cases of retained placenta, metritis, and displaced abomasum, respectively, in the sampled cows during the sampling period. No association was found between the proportion of cows in a herd that were in the high-risk metabolite concentration groups in wk −1 and the odds of retained placenta, metritis, and displaced abomasum. However, herds that had ≥25% of the animals with BHBA ≥1,400 μmol/L or ≥35% of the animals with calcium ≤2.1 mmol/L in wk +1 had higher odds of displaced abomasum after calving (Table 1). Similar results were obtained when only multiparous cows were considered in the analyses.

Milk Production

The mean (±SD) herd milk production at the first DHIA test was 35.4 (±5.0 kg/cow per day; the minimum mean was 23.6 kg/d and the maximum was 44.1 kg /d). Herds with ≥15% of the cows with BHBA ≥800 μmol/L in wk −1 or ≥15% of the cows with calcium ≤2.1 mmol/L in wk +1 had lower average milk production at the first DHIA test (Table 2). When only multiparous cows were considered, herds with ≥30% of the multiparous cows with NEFA ≥0.5 mEq/L or ≥20% of the multiparous cows with BHBA ≥800 μmol/L in wk −1, or ≥25% of the multiparous cows with calcium ≤2.1 mmol/L in wk +1 had lower average milk production at the first DHIA test.

Pregnancy at the First AI

The median proportion (and interquartile range) of cows pregnant at the first AI was 0.32 (0.25, 0.40). Herds that had ≥5% of the animals with calcium ≤2.1 mmol/L in wk −1, or ≥30% of the animals with NEFA ≥1.0 mEq/L or 25% of the animals with calcium ≤2.1 mmol/L in wk +1 had lower odds of pregnancy at first

Table 2. Herd-level associations of increased metabolite concentrations in wk −1 and +1 relative to calving with milk production (kg/d) at the first DHIA test (n = 45 herds)

Metabolite	Herd-level threshold[1] (%)	Farms above threshold (%)	Estimate (kg/d per cow)	SE	*P*-value
All cows[2]					
wk −1					
BHBA[3] ≥800 μmol/L	≥15	16	−4.4	1.7	0.01
wk +1					
Calcium ≤2.1 mmol/L	≥15	73	−3.8	1.4	0.01
Multiparous cows only					
wk −1					
NEFA[4] ≥0.5 mEq/L	≥30	36	−3.0	1.5	0.04
BHBA[3] ≥800 μmol/L	≥20	11	−5.5	2.2	0.01
wk +1					
Calcium ≤2.1 mmol/L	≥25	55	−2.9	1.4	0.05

[1]Expressed as percentage of sampled cows in the high-risk metabolite concentration group.

[2]Controlling for the proportion of primiparous cows sampled in the herd.

[3]Serum BHBA.

[4]Serum NEFA.

AI (Table 3). When only multiparous cows were considered, herds that had ≥50% of multiparous cows with NEFA ≥0.5 mEq/L in wk −1, or ≥30% of multiparous cows with NEFA ≥1.0 mEq/L in wk +1 had lower odds of pregnancy at first AI.

DISCUSSION

Several studies have reported associations at the cow level between increased serum NEFA and BHBA and decreased calcium around parturition and impaired health and productivity (Ospina et al., 2010 a,b; Chapinal et al., 2011; 2012; Seifi et al., 2011). Cow-level thresholds associated with undesirable outcomes varied across studies likely due to differences in sampling times and herd conditions. In this study, we used metabolite thresholds calculated at the cow level with the same data set (Chapinal et al., 2011, 2012) to calculate herd-level thresholds expressed as the proportion of sampled animals with increased NEFA or BHBA, or decreased calcium. Samples were only collected once per week and the actual day relative to calving was not considered when the cow-level thresholds were calculated. Therefore, the results in this study are applicable to herd-monitoring schemes that collect samples once per week. The sampling scheme used in this study (a cohort of approximately 36 cows per herd sampled over a few months) may not reflect the disease incidence for these herds for an entire year and may not allow for detection of small differences between herds in disease incidence. Given a sample size of 30, zero outcomes measured could include a maximum true incidence of 7 to 9%

Table 3. Herd-level associations of increased metabolite concentrations in wk −1 and +1 relative to calving with pregnancy at first AI (n = 48 herds)

Metabolite	Herd-level threshold[1] (%)	Farms above threshold (%)	OR[2]	CI	*P*-value
All cows					
wk −1					
Calcium ≤2.1 mmol/L	≥5	33	0.7	0.5–1.0	0.04
wk +1					
NEFA[3,4] ≥1.0 mEq/L	≥30	17	0.6	0.4–0.9	0.02
Calcium ≤2.1 mmol/L	≥25	40	0.7	0.5–0.9	0.02
Multiparous cows only					
wk −1					
NEFA[3,4] ≥0.5 mEq/L	≥50	11	0.5	0.2–0.9	0.03
wk +1					
NEFA[3,4] ≥1.0 mEq/L	≥30	23	0.6	0.4–1.0	0.04

[1]Expressed as percentage of sampled cows in the high-risk metabolite concentration group.

[2]Odds ratio; odds of pregnancy at first AI in a high-risk herd (above the herd-level threshold) compared with a low-risk herd (below the herd-level threshold).

[3]Serum NEFA.

[4]Controlling for region.

for herd sizes between 100 and 6,000 cows (Dohoo et al., 2009). Despite the possibility of underestimation of whole-herd annual disease risks, the large sample of cows from 55 herds from multiple regions provides representative estimates and herd-level thresholds that can be used in North American dairy herds.

For practical application, we used the same cow-level metabolite thresholds to determine herd-level thresholds for the different outcomes (increased incidence of disease, milk loss, and decreased pregnancy at the first AI), although Chapinal et al. (2011, 2012) found slightly different cow-level metabolite thresholds for the different outcomes. We found some differences in the associations between the metabolites and the outcomes at the cow and herd levels, suggesting the potential utility of interpreting metabolic challenges in the transition period at the herd level, where changes in diet and management are generally implemented (Oetzel, 2004). For instance, no herd-level threshold of proportion of cows in the high-NEFA group was found for the prediction of metritis and retained placenta, whereas precalving NEFA $\geq$0.3 mEq/L was a predictor of both diseases at the cow level (Chapinal et al., 2011). On the other hand, in agreement with Ospina et al. (2010c), we found that the proportion of cows with elevated postcalving NEFA concentration was associated with decreased pregnancy at the first AI at the herd level, whereas no association was found at the cow level (Chapinal et al., 2012).

Little literature exists on herd-level indicators of NEB and hypocalcemia in the transition period. Based on a literature review and clinical experience, Oetzel (2004) suggested the use of herd-level thresholds of 10% of the sampled cows with precalving NEFA $\geq$0.4 mEq/L and postcalving BHBA $\geq$1,400 μmol/L to detect herds with excessive NEB and subclinical ketosis, and 30% of the cows sampled with postcalving calcium <2.0 mmol/L to detect herds with problems of hypocalcemia. Ospina et al. (2010c) determined herd-level thresholds of 15 to 20% of the sampled cows with precalving NEFA $\geq$0.27 mEq/L, postcalving NEFA $\geq$0.60 or 0.70 mEq/L, and postcalving BHBA $\geq$1,000 or 1,200 μmol/L to detect herds with increased risk of displaced abomasum and clinical ketosis, reduced milk production, and reduced pregnancy rate. Although Ospina et al. (2010c) used lower metabolite thresholds than in the current study, the herd-level thresholds reported were lower. However, they only considered herd-level thresholds of $\leq$25% of the sampled cows. Some of the differences between the 2 studies could also be caused by the different sampling time frame in Ospina et al. (2010c; from d −14 to −3 and from d 3 to 14 relative to calving) and the smaller number of cows sampled per herd (15 or less).

Ospina et al. (2010c) found associations of the proportion of cows with elevated concentrations of precalving NEFA and postcalving NEFA and BHBA with increased incidence of disease. In the current study, the only metabolite indicator of NEB associated with incidence of disease at the herd level was BHBA $\geq$1,400 μmol/L in the week after calving for prediction of displaced abomasum, at a herd-level threshold of 25% of cows in the high-BHBA group. This is in agreement with Oetzel (2004), who suggested the same postpartum BHBA threshold for predicting cows at risk of disease, although at a lower herd-level threshold of 10%.

The proportion of cows with elevated precalving BHBA concentration was associated with decreased herd average milk production. Ospina et al. (2010c) did not consider precalving BHBA as a herd-level indicator of milk loss. Most of the literature at the cow level has focused on precalving NEFA and postcalving BHBA as indicators of detrimental outcomes (Duffield et al., 2009; Ospina et al., 2010a,b). However, BHBA concentration in the week before calving has recently been associated at the cow level with milk loss (Chapinal et al., 2012), increased risk of displaced abomasum (Chapinal et al., 2011), and culling within 60 DIM (Roberts et al., 2012). These findings suggest that precalving BHBA merits further research, particularly due to the availability of several practical cow-side tests for measuring BHBA, as opposed to NEFA (Iwersen et al., 2009).

We found significant herd-level associations of postcalving calcium concentrations with increased incidence of disease and milk loss, and of pre- and postcalving calcium concentrations with decreased pregnancy at the first AI. The cow-level threshold of $\leq$2.1 mmol/L used in this study is similar to the threshold of <2.0 mmol/L suggested by Oetzel (2004) and Reinhardt et al. (2011) to define subclinical hypocalcemia in the 48 h following parturition. Although the present samples were collected throughout the week before and the week after calving, serum calcium concentrations are expected to decrease after calving and increase by 4 DIM (Melendez et al., 2002). The threshold of $\leq$2.1 mmol/L is within the wide range (1.64–2.61 mmol/L) for cows sampled in the first week after calving that had no clinical disease in the transition period (Quiroz-Rocha et al., 2009). This suggests that even mild hypocalcemia may be associated with, or be an indicator of, compromised metabolic health.

Some differences were observed in the herd-level thresholds for the prediction of milk loss and decreased pregnancy at first AI when only multiparous cows were assessed, in agreement with Ospina et al. (2010c). This is not surprising because some of the associations found at the cow level were only significant for multiparous cows (Chapinal et al., 2012), and physiological differences exist between primiparous and multiparous cows in the way they cope with the increased energy and calcium demands in the transition period.

CONCLUSIONS

Herd-level thresholds of 5 to 50% of the sampled animals with increased NEFA or BHBA or decreased calcium in the week before and after calving were associated with higher risk of displaced abomasum, milk loss at the first DHIA, and decreased pregnancy at first AI. The association found between precalving BHBA and milk production is promising due to the availability of several cow-side tests for measuring BHBA. Some of the herd-level associations between the metabolites and the outcomes differed from the previously described cow-level associations, suggesting the potential utility of interpreting metabolic challenges in the transition period at the herd level. Further research is needed to understand how these herd-level thresholds can be applied to monitor NEB and hypocalcemia at the herd level, as well as to make decisions on herd nutrition and management.

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