Prevalence of early postpartum health disorders in Holstein cows and associations with production, reproduction, and survival outcomes on Alberta dairy farms

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Abstract — The objective of this study was to determine the prevalence and associations of early postpartum health disorders with production, reproduction, and survivability in dairy cows in Alberta. Holstein cattle (N = 1096) from 11 commercial dairy farms in Alberta, Canada were enrolled. Cows were evaluated daily for clinical postpartum health disorders and a blood sample was collected once within 2 wk after calving to diagnose subclinical disorders. Overall, 61% of cows were diagnosed with at least 1 postpartum health disorder, with 25% of cows having multiple disorders. Of the cows with only 1 health disorder, 71% were classified as inflammatory and 29% as metabolic disorders. Cows with multiple disorders were at the greatest risk of reduced milk production, impaired fertility, and leaving the herd. Cows with an inflammatory disorder had reduced productive and reproductive performance, whereas cows with a metabolic disorder were at the greatest risk of mortality.

Résumé — Prévalence des troubles de santé post-partum précoces chez les vaches Holstein et associations avec les résultats de production, de reproduction et de survie dans les fermes laitières de l'Alberta. L'objectif de la présente étude était de déterminer la prévalence et les associations des troubles de santé post-partum précoces avec la production, la reproduction et la capacité de survie chez les vaches laitières en Alberta. Des bovins Holstein (N = 1096) de 11 fermes laitières commerciales en Alberta, au Canada, ont été recrutés. Les vaches ont été évaluées quotidiennement pour des problèmes cliniques de santé post-partum et un échantillon de sang a été prélevé une fois dans les 2 semaines après le vêlage pour diagnostiquer les problèmes subcliniques. Dans l'ensemble, 61 % des vaches ont reçu un diagnostic d'au moins un problème de santé post-partum, 25 % des vaches ayant des problèmes multiples. Parmi les vaches présentant un seul problème de santé, 71 % ont été classées comme inflammatoires et 29 % comme des problèmes métaboliques. Les vaches souffrant de problèmes multiples couraient le plus grand risque de réduction de la production de lait, d'impact sur la fertilité et d'élimination du troupeau. Les vaches présentant un problème inflammatoire avaient des performances de production et de reproduction réduites, tandis que les vaches présentant un problème métabolique étaient les plus exposées au risque de mortalité.

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Introduction

The transition period, 3 wk before to 3 wk after calving, is a stressful time for dairy cattle, with nearly all cattle experiencing reduced feed intake, negative energy balance, reduced immune function, and bacterial contamination of the uterus (1). In a study evaluating 2 commercial dairy farms in Florida, 37.5% of cows were diagnosed with a clinical health disorder postpartum and 59% of cows were diagnosed with a subclinical disorder (2). With such a large proportion of cattle likely to develop a postpartum health disorder, there is a considerable impact on both animal welfare and the economic performance of a dairy farm (1). Each disorder can result in a direct cost of diagnosis, treatment, labor, and discarded milk; however, there is also the risk of increased loss due to impaired production and reproduction. In a recent study, Carvalho et al (3) determined that 30% of cows developed a clinical health disorder within 21 days in milk (DIM), which resulted in decreased milk production, decreased reproductive efficiency, and increased likelihood of death, culling or being sold.

Although postpartum health disorders in general have a carryover effect on performance, there may also be an effect of type of disorder. Inflammatory diseases, such as retained fetal membranes, mastitis, and uterine diseases, reduce pregnancy rates, impair conceptus development, and increase embryo losses (4).

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In addition, increased circulating concentrations of haptoglobin, indicative of inflammation, are also associated with impaired fertility and reduced milk yields (5–6). Metabolic disorders, such as hypocalcemia, ketosis, and displaced abomasum, have a more variable effect on fertility and milk production (2,7–9). However, there is ample evidence that increased negative energy balance, associated with increased circulating concentrations of non-esterified fatty acid (NEFA) and beta-hydroxybutyrate (BHB), is related to reduced risk of conception (10,11). There are few studies that assess the impact of various types of postpartum health disorders on production, reproduction, and survivability. In western Canadian dairy herds, there are few studies on the prevalence of specific postpartum health disorders. The objective of this study, therefore, was to determine the prevalence and types of postpartum health disorders in early lactation dairy cows and associations with production, reproduction, and survivability in dairy herds in Alberta.

Materials and methods

Study design

This prospective observational study was conducted using field data collected between April 2015 and November 2015 on 11 commercial dairy herds located in Alberta, Canada. Herd-selection criteria have been described in Gobikrushanth et al (12). Briefly, each herd had ≥ 100 lactating cows, free stall housing, and used either CanWest DHI (dairy herd improvement) or DairyComp 305 (Valley Agricultural Software, Tulare, California, USA) milk recording services. All procedures were conducted in accordance with guidelines of the Canadian Council on Animal Care (13).

Cattle, housing, and herd management

A total of 1096 Holstein cattle (328 primiparous and 768 multiparous) were enrolled in this study. Housing and nutritional management have been described in the publication by Gobikrushanth et al (12).

Diagnosis of postpartum health disorders

Cows were observed for retained fetal membranes (RFM), metritis, displaced abomasum (DA), hypocalcemia (clinical and subclinical), ketosis (clinical and subclinical), and mastitis (clinical and subclinical) from calving to 60 DIM. Research team members visited each herd every other week to collect the standard forms. Definitions of the health disorders have been published by Gobikrushanth et al (12). Subclinical mastitis was diagnosed if a milk sample had a somatic cell count (SCC) ≥ 200 000/mL at the first or second DHI test (14). Cows with at least 1 documented postpartum health disorder were considered sick and those with only 1 documented postpartum health disorder were further classified as INF (i.e., RFM, metritis, or mastitis) or MET (i.e., hypocalcemia or ketosis). Specific subclinical and clinical disorder diagnoses were only used to describe the prevalence of specific health disorders among primiparous and multiparous cows. When determining the associations of health disorders with production, reproduction, and survivability, subclinical and clinical cows were considered as having the same disorder, i.e., hypocalcemia, ketosis, or mastitis.

Determination of body condition scores (BCS) and serum concentrations of analytes

The body condition scores (BCS) were assessed by 2 well-trained technicians at 9.0 ± 2.3 d (mean ± SD) before calving. A single blood sample was collected between 2 and 14 DIM by research team members during bi-weekly farm visits. Blood was collected from the coccygeal vessels and placed into vacuum tubes containing no preservative (Vacutainer; Becton Dickinson, Franklin Lakes, New Jersey, USA). Samples were left at room temperature for 3 to 4 h, then centrifuged, serum separated frozen, and stored at −20°C until submission to the Animal Health Laboratory (AHL; University of Guelph, Guelph, Ontario) for determination of serum concentrations of Ca, BHB, and haptoglobin. All assays were conducted at the AHL, as described by Gobikrushanth et al (12).

Blood samples were used to diagnose subclinical hypocalcemia and ketosis. Cows without signs of sickness and having a postpartum serum calcium (Ca) concentration ≤ 2.10 mmol/L were considered as having subclinical hypocalcemia (15,16). Cows without signs of sickness with postpartum serum concentration of BHB ≥ 1.1 mmol/L were considered as having subclinical ketosis (17).

Data collection and determination of production and reproductive outcomes

Data regarding parity, sex of calf, twin birth, month of calving, death, sold and culling rates, milk production parameters [lactation length, milk yield by 25 and 90 DIM, peak and 305-day mature-equivalent (ME) milk yields] and reproductive events [pregnancy outcome after first artificial insemination (AI), pregnancy status by 150 DIM and pregnancy loss] for the current lactation were retrieved using DairyComp 305 herd management software. Details on herd reproductive management have been published by Macmillan et al (5). Transrectal ultrasonography was done by the herd veterinarian at 30 to 35 d post-AI to determine pregnancy status. Presence of a viable embryo (positive heartbeat) was used as a determinant of pregnancy. Cows diagnosed as pregnant at first examination were re-examined 3 to 5 wk later to confirm pregnancy. Pregnancy loss was defined as a cow diagnosed pregnant at first ultrasound examination and not pregnant at re-examination.

Statistical analyses

Data were analyzed using SAS version 9.4 (SAS Institute, Cary, North Carolina, USA). The descriptive statistics for proportion of cows categorized as healthy, diagnosed with 1 or ≥ 2 postpartum health disorders and by INF and MET within those diagnosed as having 1 postpartum health disorder were compared among farms using GLIMMIX procedure. The differences in the prevalence of postpartum health disorders between primiparous and multiparous cows were compared by Chi-square analysis using FREQ procedure.

The factors associated with postpartum sickness were tested in 2 separate models. In the first model, the associations among categories of parity (primiparous and multiparous), pre-calving BCS [low (≤ 2.75), moderate (3.00 to 3.50), and high (≥ 3.75)], and calving ease (unassisted and assisted), calf

Table 1. Number of cows categorized as healthy, diagnosed with only 1 or ≥ 2 postpartum health disorders and by disorder classification (inflammatory or metabolic) for each farm enrolled.

	Health status category[a]			Disorder classification[b]	
Farm	Healthy	1 Disorder	2+ Disorders	INF	MET
1 (n = 36)	8	11	17	7	4
2 (n = 202)	73	79	50	68	11
3 (n = 144)	61	49	34	33	16
4 (n = 52)	18	16	18	6	10
5 (n = 63)	31	25	7	16	9
6 (n = 28)	10	10	8	6	4
7 (n = 140)	71	39	30	26	13
8 (n = 147)	40	53	54	40	13
9 (n = 122)	38	56	28	41	15
10 (n = 117)	48	46	23	31	15
11 (n = 45)	27	12	6	7	5
Total (n = 1096)	425	396	275	281	115

[a] All cows from each farm were evaluated daily for health status up to 60 days in milk and a blood sample was taken between 2 to 14 days after calving to diagnose subclinical disorders. Postpartum health disorders diagnosed include retained fetal membranes, metritis, displaced abomasum, hypocalcemia (clinical and subclinical), ketosis (clinical and subclinical), and mastitis (clinical and subclinical). Cows were categorized as healthy, diagnosed with 1 or with ≥ 2 postpartum health disorders.

[b] All cows diagnosed with only 1 postpartum health disorder were further classified based on disorder diagnosis. An inflammatory (INF) classification included retained fetal membranes, metritis and mastitis, whereas a metabolic (MET) classification included hypocalcemia and ketosis.

outcome (female, male, twin), season of calving [hot (June, July, and August) and cold (April, May, September, October, and November)], and postpartum sickness (healthy or diagnosed as having at least 1 postpartum health disorder) were first determined in all 1096 cows. In the second model, the effect of previous lactation 305-day ME milk yield [classified as high (> 10 900 kg) or low (≤ 10 900 kg) based on the average previous lactation 305-day ME milk yield of 10 900 kg and length of dry period classified as longer (> 60 d) or optimum (≤ 60 d)] was tested along with the aforementioned fixed effects (pre-calving BCS, calving ease, calf outcome, and calving season) in a subset of 766 cows that had complete previous lactation data available. The model specifications included a binomial distribution, logit function, an option to estimate odds ratios, whereas the effect of farm was treated as random.

The associations among categories of postpartum health status (healthy, 1, and ≥ 2 health disorders) or disorder classification (healthy, INF, and MET), parity (primiparous and multiparous) and survival (death, cull, and sold by 90 DIM) and milk production parameters (milk yield by 25 DIM, at peak and by 90 DIM, 305-day ME milk yield, and lactation length) were determined using GLIMMIX procedure. The binomial continuous dependent variables were initially modelled against categories of postpartum health status or disorder classification, parity, and their interactions. As none of the interactions were significant, the final model only included categories of postpartum health status or disorder classification and parity, whereas the effect of farm was treated as random. The differences in least square means among levels, within each factor, were compared using the Tukey-Kramer multiple means comparison test.

The associations among categories of postpartum health status or disorder classification and reproductive outcomes [pregnant to first AI (PAI1), pregnant by 150 DIM (P150), pregnancy loss after first AI (PL1) or any AI (PL2), and number of days open] were determined using GLIMMIX procedure. The binomial and continuous dependent variables (reproductive outcomes) were initially modelled against categories of postpartum health status or disorder classification, parity, and their interactions. As none of the interactions were significant, the final model only included categories of postpartum health status or disorder classification and parity, whereas the effect of farm was treated as random. The differences in least square means among levels within each factor were compared using the Tukey-Kramer multiple means comparison test.

The differences in interval from calving to pregnancy risk up to 150 DIM among categories of postpartum health status were evaluated by the Kaplan-Meier survival analysis, using LIFETEST procedure. A Cox proportional hazard model using PHREG procedure confirmed the results from Kaplan-Meier survival analysis. Significant differences were reported if $P \leq 0.05$ and considered to be a tendency if $P > 0.05$ and ≤ 0.10.

Results

From the 1096 cows included in the final analysis, the proportion of cows in each health status category and for each postpartum health disorder classification by farm are shown in Table 1. The prevalence rates of specific postpartum health disorders were: 6.9% RFM, 14.8% metritis, 0.9% DA, 5.8% clinical ketosis, 9.5% subclinical ketosis, 3.0% clinical hypocalcemia, 21.4% subclinical hypocalcemia, 12.4% clinical mastitis, and 25.2% subclinical mastitis. The percentages of primiparous and multiparous diagnosed with at least 1 postpartum health disorder were 58.2% and 62.5%, respectively. The proportion of cows with each postpartum health disorder diagnosis by parity is shown in Table 2.

The associations between independent factors and likelihood of cows being diagnosed with at least 1 postpartum health disorder within 60 DIM are shown in Table 3. Although parity,

Table 2. Percentages of primiparous and multiparous cows diagnosed with a postpartum health disorder by 60 days in milk by disorder diagnosis.[a]

Postpartum health disorder	Primiparous (n = 328)	Multiparous (n = 768)	P-value
Retained fetal membranes	6.4 (21)	7.2 (55)	0.65
Metritis	17.1 (56)	13.8 (106)	0.10
Displaced abomasum	0.9 (3)	0.9 (7)	0.83
Ketosis			
Clinical	4.0 (13)	6.5 (50)	0.09
Subclinical	6.1 (20)	10.9 (84)	0.01
Hypocalcemia			
Clinical	0.9 (3)	3.9 (30)	< 0.01
Subclinical	17.1 (56)	23.3 (179)	0.02
Mastitis			
Clinical	7.6 (25)	14.5 (111)	< 0.01
Subclinical	20.7 (68)	27.1 (208)	0.03

[a] Cows from each farm were evaluated daily for clinical postpartum health disorders including retained fetal membranes (RFM), metritis, displaced abomasum (DA), ketosis, hypocalcemia, and mastitis. Diagnosis criteria for clinical health disorders are described in Gobikrushanth et al (12). In addition, a blood sample was taken from 2 to 14 days after calving to diagnose subclinical ketosis (BHB ≥ 1.1 mmol/L) and hypocalcemia (Ca ≤ 2.1 mmol/L). Subclinical mastitis was diagnosed by a milk sample having ≥ 200 000 somatic cells/mL at the first DHI test.

pre-calving BCS, and calving season were not associated with postpartum sickness, both calving ease and calf outcome were significantly associated with postpartum sickness. In this regard, cows that were assisted at calving had 1.7 increased odds of being diagnosed with a postpartum health disorder compared to cows that were unassisted at calving. In addition, compared to giving birth to a female calf, giving birth to twins increased the odds of being diagnosed with a postpartum health disorder by 5.1, with no difference between birthing female or male calves. In the subset of 766 cows that were 2nd parity or greater, there were no associations between pre-calving BCS, calving ease, calf outcome, calving season, or previous 305-day ME milk yield and sickness after calving. However, length of the previous dry period was associated with sickness, with cows with a dry period of > 60 d having 1.9 greater odds of being diagnosed with at least 1 postpartum health disorder compared to cows having a dry period of ≤ 60 d ($P < 0.01$).

The production, reproduction, and survival outcomes by health status category are shown in Table 4. Healthy cows had the greatest cumulative milk yield at 25 DIM, with cows diagnosed with ≥ 2 postpartum health disorders having the least and cows diagnosed with only 1 postpartum health disorder being intermediate. By 90 DIM, the cumulative milk yield was greater in healthy cows compared to cows diagnosed with ≥ 2 postpartum health disorders, with no difference in peak milk yield by health status category. The 305-day ME yield was greater in healthy cows compared to all other categories, whereas current lactation length was only greater in healthy cows compared to cows diagnosed with ≥ 2 postpartum health disorders. Regarding reproduction outcomes, cows that were diagnosed as healthy or with only 1 postpartum health disorder had greater PAI1 compared to cows diagnosed with 2 or more postpartum health disorders. Compared to healthy cows, cows diagnosed with 2 or more postpartum health disorders had lower P150 and increased number of days open, with cows diagnosed with only 1 postpartum health disorder being intermediate. The probability of pregnancy up to 150 DIM by postpartum health status category is shown in Figure 1. In this regard, healthy cows and cows diagnosed as having 1 postpartum health disorder had 1.4 and 1.3 times, respectively, greater risk of pregnancy up to 150 DIM compared to those diagnosed as having 2 or more postpartum health disorders. There was no difference in PL1 or PL2 by health status category. Healthy cows had a reduced death rate by 90 DIM compared to cows diagnosed with 1 and 2 or more postpartum health disorders, whereas cows diagnosed with 2 or more disorders had an increased culling rate by 90 DIM compared to the other categories. There was no difference in rate of being sold by 90 DIM by health status category.

The production, reproduction, and survival outcomes by postpartum health disorder classification are shown in Table 5. All milk production outcomes were greater in healthy and cows classified as MET compared to cows classified as INF. However, cows with a MET disorder had the shortest current lactation length compared to all other classifications. There was no difference based on disorder classification (healthy, INF, MET) for PAI1 or PL1. For cows diagnosed with an INF disorder, there was a tendency for reduced P150 and a significant increase in days open compared to both healthy cows and cows diagnosed with a MET disorder. In addition, cows classified as MET had a lesser PL2 compared to healthy cows but did not differ from those classified as INF. Cows classified as MET had an increased death and selling rate by 90 DIM compared to healthy cows, with cows classified as INF being intermediate. There was no difference in cull rate by 90 DIM by postpartum health disorder classification.

Discussion

The objective of the current study was to diagnose common clinical and subclinical postpartum health disorders in dairy cows and determine their associations with production, reproduction, and survivability. Milk production was reduced in cows having at least 1 postpartum health disorder, but cows with ≥ 2 disorders had lower milk production and impaired reproductive performance, compared to healthy cows. Cows with at least 1 postpartum health disorder had increased risk of dying, whereas cows with ≥ 2 disorders also had increased risk of culling, compared to healthy cows. Of the cows that were diagnosed with only 1 postpartum health disorder, cows with an inflammatory disorder had reduced milk production and reproductive performance compared to healthy cows. Cows with a metabolic disorder were at an increased risk of dying.

From the 11 commercial dairy farms enrolled, the average proportion of cows diagnosed with at least 1 postpartum health disorder was 61% (range: 40 to 78%). This was similar to the average of 36% and 59% of cows diagnosed with a clinical and subclinical disorder, respectively, on 2 commercial dairy farms in Florida (2). The prevalence of specific postpartum health disorders was similar to reports from Koeck et al (18), who reported prevalence rates of 12.6, 4.5, 4.6, and 10.8% for clinical mastitis, clinical ketosis, RFM and metritis, respectively,

Table 3. The association among independent variables included in the final model and occurrence of at least 1 postpartum health disorder after calving in all 1096 cows.

Variable	Proportion sick[a] % (numbers)	Odds ratio estimates	95% confidence interval	*P*-value
Parity				
Multiparous	62.5 (480/768)	1.2	0.93 to 1.63	0.15
Primiparous	58.2 (191/328)	Reference		
Pre-calving BCS[b]				
High	60.7 (179/295)	1.1	0.55 to 1.58	0.96
Moderate	60.7 (431/710)	1.2	0.53 to 1.39	0.80
Low	67.0 (61/91)	Reference		
Calving ease				
Assisted	65.4 (223/341)	1.7	1.19 to 2.32	< 0.01
Unassisted	59.3 (448/755)	Reference		
Calf outcome				
Twin	87.5 (21/24)	5.1	1.47 to 17.6	0.01
Male	63.1 (362/574)	1.2	0.96 to 1.59	0.23
Female	57.8 (288/498)	Reference		
Calving season[c]				
Hot	59.7 (264/442)	0.9	0.69 to 1.16	0.40
Cold	62.2 (407/654)	Reference		

[a] All cows from each farm were evaluated daily for health status up to 60 DIM and a blood sample was taken between 2 to 14 d after calving to diagnose subclinical disorders. Postpartum health disorders diagnosed include retained fetal membranes, metritis, displaced abomasum, hypocalcemia (clinical and subclinical), ketosis (clinical and subclinical), and mastitis (clinical and subclinical).

[b] BCS score was evaluated by trained veterinarians on a 5-point scale at 9.0 ± 2.3 days before calving. Cows were categorized as high (BCS ≥ 3.75), medium (3.00 to 3.50), or low (BCS ≤ 2.75).

[c] The hot season includes the months of June, July, and August, whereas the cold season includes the months of April, May, September, October, and November.

Table 4. Reproduction, survival, and production outcomes based on postpartum health status category[a] determined up to 60 days in milk (DIM).

Outcome[b]	Healthy	1 Disorder	2+ Disorders	± SEM	*P*-value
n (%)	425 (39.8)	396 (36.1)	275 (25.1)		
PAI1 (%)	37.9[x]	33.3[x]	21.1[y]	0.2	< 0.01
P150 (%)	58.6[x]	53.5[xy]	40.4[y]	0.5	0.02
Days open (d)	120[x]	127[xy]	135[y]	5.0	0.04
PL1 (%)	3.5	4.0	2.2	0.5	0.62
PL2 (%)	6.1	8.1	3.6	0.4	0.13
Death by 90 DIM (%)	1.6[x]	4.8[y]	7.3[z]	0.4	< 0.01
Cull by 90 DIM (%)	2.6[x]	3.8[x]	10.9[y]	0.4	< 0.01
Sold by 90 DIM (%)	4.5	6.6	8.0	0.3	0.22
MY 25 DIM (kg)	800[x]	755[y]	705[z]	14	< 0.01
MY 90 DIM (kg)	3359[x]	3283[xy]	3189[y]	47	< 0.01
Peak MY (kg/d)	42.3	41.8	41.3	0.6	0.21
305-day ME MY (kg)	10 855[x]	10 455[y]	10 467[y]	169	0.01
Lactation length (d)	309[x]	298[xy]	283[y]	9.0	0.01

[x,y,z] Within a row, values without a common superscript differ ($P < 0.05$).

[a] All cows from each farm were evaluated daily for health status up to 60 DIM and a blood sample was taken between 2 to 14 d after calving to diagnose subclinical disorders. Postpartum health disorders diagnosed include retained fetal membranes, metritis, displaced abomasum, hypocalcemia (clinical and subclinical), ketosis (clinical and subclinical), and mastitis (clinical and subclinical). Cows were categorized as healthy, diagnosed with 1 or with ≥ 2 postpartum health disorders.

[b] PAI1 = pregnant to first artificial insemination (AI); P150 = pregnant by 150 DIM; PL1 = pregnancy loss after first AI; PL2 = pregnancy loss after any AI; MY 25 = cumulative milk yield at 25 DIM; MY 90 = cumulative milk yield by 90 DIM; 305-day ME MY = 305-day mature equivalent milk yields.

from Canadian Dairy Network data. However, the incidence of DA in the current study was lower than the 3.7% reported by Koeck et al (18). In addition, Rodriguez et al (8) reported a similar prevalence of clinical hypocalcemia of 4.0%. The prevalence of subclinical hypocalcemia in the current study was similar to the 25% determined from cows sampled at 4 DIM by Neves et al (19), but the prevalence of subclinical ketosis was less than the 43% (20) and 40% (2) reported in previous studies. This may be due to only 1 blood sampling time point in the current study, whereas the previously mentioned studies had 6 and 2 sampling time points, respectively. The prevalence of subclinical mastitis in the current study was also similar to previous findings in Canadian dairy herds (21). It is important to note that when comparing the current results to previous literature, there was a difference between studies in location, number of farms enrolled, farm selection criteria, and farm

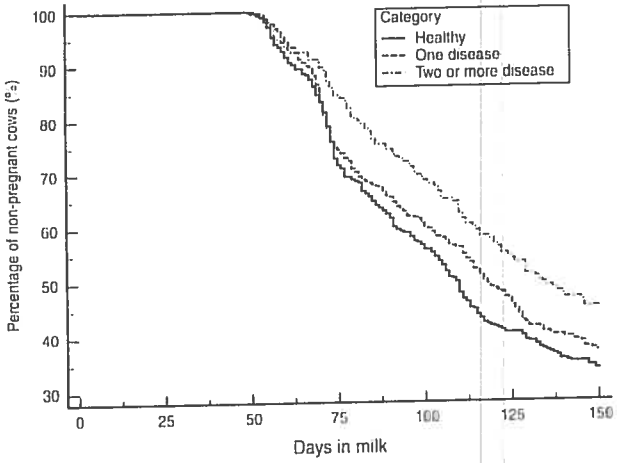

Figure 1. Kaplan-Meier survival curve illustrating the probability of pregnancy up to 150 DIM by postpartum health status categories (diagnosed as healthy or having 1 or ≥ 2 postpartum health disorders) in 1096 lactating dairy cows. The overall hazard of pregnancy up to 150 DIM significantly differed between postpartum health status categories ($P < 0.01$). Healthy cows and cows diagnosed as having 1 postpartum health disorder had 1.4 (95% CI: 1.1 to 1.8; $P < 0.01$) and 1.3 (95% CI: 1.0 to 1.6; $P = 0.03$) times, respectively, greater hazard of pregnancy by 150 DIM compared to those diagnosed as having ≥ 2 postpartum health disorders.

management, among other variables. This could have influenced any differences noted between studies; however, the overall incidences of specific disorders were similar among studies and are likely representative of the general dairy herd population. Although the overall prevalence of at least 1 postpartum health disorder did not differ between primiparous and multiparous cows (58.2 *versus* 62.5%; $P = 0.15$), there was a difference in the distribution of specific disorder diagnoses. The proportion of primiparous cows was less for ketosis, hypocalcemia, and mastitis, and tended to be higher for metritis. The sample size used was adequate for determining differences in the proportion of health disorders between primiparous and multiparous cows. Older cows have previously been associated with increased risk of mastitis (19), hypocalcemia (8), and ketosis (22), and a lower risk of metritis (23). Despite a greater proportion of multiparous cows having increased prevalence of most disorders, there was no association between parity and likelihood of developing at least 1 postpartum health disorder.

In addition to parity not being associated with likelihood of at least 1 postpartum health disorder, pre-calving BCS and calving season were also not associated with risk of a health disorder after calving. In a previous study, a greater BCS pre-calving (> 3.0) was associated with greater BCS loss after calving and an increased number of health events, considering clinical metritis, mastitis, ketosis, and pneumonia (24). The lack of association in the current study could have been due to the wide array of both clinical and subclinical postpartum health disorders considered. Although season has previously been associated with increased prevalence of postpartum health disorders like RFM (25) and hypocalcemia (26), again the wide array of disorders considered may have affected the association with season in the current study. Results should also be interpreted with caution, as data were only collected from April to November and not during the coldest part of the year. In addition, heat stress in western Canada is less than that in other areas. Conversely, a calving requiring assistance and birth of twins was associated with increased likelihood of at least 1 postpartum health disorder, by a factor of 1.7 and 5.1, respectively. This was unsurprising, as calving problems, including dystocia and twin births, have been previously associated with DA (27), RFM (28), uterine disease (2), and systemic inflammation (6). The sample size in the current study may have been too small to detect significant differences in this analysis. Overall, the results still suggest that cows requiring assistance during calving or those birthing twin calves should be monitored closely postpartum for health disorders.

The occurrence of postpartum health disorders was associated with reduced milk yield at 25, 90, and 305 DIM, and 2 or more health disorders were associated with a further reduction in milk yield. All milk production outcomes were only reduced in cows with an INF disorder compared to healthy cows. The sample size used was adequate for determining differences for continuous outcomes of milk production; however, the data represented an association and not cause and effect. In a recent study from a commercial farm in Florida, cows diagnosed with clinical health disorders by 21 DIM also had reduced milk production at 30, 60, 90, and 305 DIM, with a greater reduction in cows with more than 1 clinical disorder (3). Shin et al (6) reported that cows with high circulating concentrations of haptoglobin, indicating inflammation, also had reduced milk yield. In the current study, the postpartum health disorder that affected the most cows was clinical and subclinical mastitis, which would be most likely to have a direct effect on milk production. Although cows with a MET disorder were not associated with production in the current study, previous studies measuring NEFA and BHB, indicating negative energy balance and associated with metabolic disorders (29), reported differing associations on milk production based on parity (10). Increased circulating concentrations of these metabolites were associated with increased 305-day milk production in primiparous cows and lower 305-day milk production in multiparous cows (10). Cows with ≥ 2 postpartum health disorders and those diagnosed with a MET disorder had a shorter lactation, which may be due to an increased death and/or culling rate, as discussed below. In addition to being associated with impaired reproduction, cows with 2 or more postpartum health disorders and those with an INF disorder are also at a greater risk for reduced productive performance.

Only cows with 2 or more postpartum health disorders had reduced overall fertility compared to healthy cows. The sample size used was adequate for determining differences for continuous and binomial outcomes of reproduction; however, the data represent an association and not cause and effect. Recently, Carvalho et al (3) reported that cows diagnosed with a clinical postpartum health disorder within 21 DIM had reduced pregnancy per AI and greater pregnancy loss, regardless of number of disorders. Ribeiro et al (2), however, supported the current study, stating that cows with > 1 postpartum health disorder had reduced pregnancy per AI and a numerically greater rate

Table 5. Reproduction, survival, and production outcomes based on postpartum health disorder classification[a] (inflammatory or metabolic) from cows with only 1 diagnosed health disorder.

Outcome (%)[b]	Healthy	INF	MET	± SEM	*P*-value
n (%)	425 (38.8)	396 (36.1)	275 (25.1)		
PAI1	37.9	32.7	34.8	0.2	0.39
P150	58.6[x]	52.3[y]	56.5[x]	0.3	0.10
Days open (d)	123[x]	134[y]	114[x]	7.0	0.01
PL1	3.5	5.0	1.7	0.8	0.26
PL2	6.1[xy]	9.9[y]	3.5[x]	0.6	0.04
Death by 90 DIM	1.6[x]	2.1[x]	10.9[y]	0.6	< 0.01
Cull by 90 DIM	2.6	3.9	3.5	0.6	0.61
Sold by 90 DIM	2.8[x]	6.0[y]	0.9[x]	0.7	< 0.01
MY 25 DIM (kg)	793[x]	722[y]	807[x]	20	< 0.01
MY 90 DIM (kg)	3351[x]	3200[y]	3444[x]	63	< 0.01
Peak MY (kg/d)	42.2[x]	41.0[y]	43.6[x]	0.8	< 0.01
305-day ME MY (kg)	10 801[x]	10 277[y]	10 654[x]	232	< 0.01
Lactation length (d)	307[x]	304[x]	272[y]	12	< 0.01

[x,y] Within a row, values without a common superscript differ ($P < 0.05$).
[x,y] Within a row, values without a common superscript tended to differ ($0.05 < P \leq 0.10$).
[a] All cows from each farm were evaluated daily for health status up to 60 DIM and a blood sample was taken between 2 to 14 d after calving to diagnose subclinical disorders. Postpartum health disorders diagnosed include retained fetal membranes, metritis, displaced abomasum, hypocalcemia (clinical and subclinical), ketosis (clinical and subclinical), and mastitis (clinical and subclinical). Cows with only 1 postpartum health disorder were further classified based on disorder diagnosis. Inflammatory (INF) classification included retained fetal membranes, metritis and mastitis, whereas metabolic (MET) classification included hypocalcemia and ketosis.
[b] PAI1 = pregnant to first artificial insemination (AI); P150 = pregnant by 150 DIM; PL1 = pregnancy loss after first AI; PL2 = pregnancy loss after any AI; MY 25 = cumulative milk yield at 25 DIM; MY 90 = cumulative milk yield by 90 DIM; 305-day ME MY = 305 day mature equivalent milk yields.

of pregnancy loss. The main difference between the studies is that Ribeiro et al (2) and the current study considered both clinical and subclinical disorders, whereas Carvalho et al (3) only considered clinical disorders. In the current study, only cows classified with an INF disorder tended to have a reduced P150 and had significantly greater days open and pregnancy loss after AI compared to healthy cows. There was also a greater prevalence of INF disorders compared to MET disorders in the current study. It should be noted that once cows were subcategorized based on disorder classification, sample size may not have been large enough to detect significant differences. The occurrence of inflammatory disorders before AI has been associated with reduced fertilization of oocytes and impaired early conceptus development (4). In addition, inflammatory disorders also caused inflammation-like changes in conceptus cell gene expression and increased odds of pregnancy loss (4). In a study comparing cows with high or low circulating haptoglobin concentrations postpartum, cows with high haptoglobin, indicating increased inflammation and reduce immune function (30), had a reduced risk of pregnancy and increased days open (6). In results published from the same dataset used in the current study, Macmillan et al (5) also reported a negative association between increased circulating concentrations of haptoglobin and PAI1. It should be noted that although MET disorders in the current study were not associated with reduced fertility, previous studies have reported that MET disorders and increased negative energy balance are related with reduced reproductive performance (2,11). In addition, Macmillan et al (5) also reported that increased circulating concentrations of aspartate aminotransferase and NEFA and reduced concentrations of cholesterol, indicating increased fat mobilization, impaired liver function and reduced dry matter intake, were associated with lower PAI1. Overall, cows with more than 1 postpartum health disorder and those with an INF disorder may have impaired reproductive performance.

The proportion of cows with 2 or more postpartum health disorders that left the herd (died, culled, sold) by 90 DIM was 26.2%, compared to 15.2% of cows with only 1 disorder and 8.7% of healthy cows. It should be noted that the sample size in the current study may not have been large enough to detect small differences between groups in survivability and to identify weaker associations. In addition, as cows with severe illness were more likely to leave the herd, their effect on production and reproductive outcomes were diminished, which may have resulted in an underrepresentation of the effect of a postpartum health disorder on the performance of cows in the current study. Carvalho et al (3) reported increased mortality with diagnosis of at least 1 clinical health disorder, as well as increased risk of culling and selling with a clinical disorder diagnosis, which was greater with more than 1 clinical disorder. In addition, Ribeiro et al (2) observed a greater proportion of cows leaving the herd after a clinical disorder diagnosis, with no difference after a subclinical diagnosis. In the current study, cows with a MET health disorder were at a much greater risk of dying, indicating that monitoring metabolic health in the transition period is vital. In a large-scale study, Roberts et al (31) identified postpartum health disorders that were factors of culling risk by 60 DIM, which were RFM, ketosis, DA, and hypocalcemia. In addition, increased concentrations of NEFA, indicative of a negative energy balance and metabolic disorders (29), around the time of calving, were associated with an increased death rate in multiparous cows (10). Regarding the proportion of cows sold in the

current study, the reason for selling was not accurately recorded, but the decrease in reproductive and productive performance in cows with an INF disorder, may have resulted in the greater prevalence of selling.

In conclusion, an average of 61% of cows from 11 commercial farms in Alberta were diagnosed with at least 1 postpartum health disorder and 25% had ≥ 2. Of the cows that were diagnosed with only 1 postpartum health disorder, 71% were classified as having an inflammatory disorder and 29% as having a metabolic disorder. Overall, the development of a postpartum health disorder, especially more than 1, and development of an inflammatory disorder were associated with reduced milk production, decreased reproductive performance, and increased likelihood of leaving the herd. Cows diagnosed with a postpartum health disorder should be carefully managed to reduce the negative impact on performance during their lactation.

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