First-lactation performance in cows affected by digital dermatitis during the rearing period

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ABSTRACT

The long-term effects of prepartum digital dermatitis (DD) on first-lactation performance were evaluated in a cohort of 719 pregnant heifers. All heifers were followed for a period of 6 mo until calving and classified on the basis of the number of DD events diagnosed during this period as type I, type II, or type III (no DD, one DD event, and multiple DD events, respectively). Health during the initial 60 d in milk (DIM), reproductive and hoof health outcomes, and milk production were compared between the 3 heifer type groups. All logistic and linear models were adjusted for age, height, and girth circumference at enrollment, and the type of trace mineral supplementation during the prepartum period. Overall, cows experiencing DD during the rearing period showed worse production and health outcomes compared with healthy heifers during the first lactation. The percentages of assisted calvings, stillbirths, culled before 60 DIM, and diseased cows during the fresh period were numerically higher in type III cows compared with type I cows. However, none of these differences were statistically significant at the 95% confidence level. Significantly lower conception at first service [odds ratio (OR) = 0.55, 95% confidence interval (95% CI): 0.33, 0.89] and increased number of days open (mean = 24 d, 95% CI: 5.2, 43) were observed in type III cows compared with type I cows. In relation to hoof health, a significantly increased risk of DD during the first lactation was found in type II and III cows (OR = 5.16, 95% CI: 3.23, 8.29; and OR = 12.5, 95% CI: 7.52, 21.1, respectively), as well as earlier occurrence of DD following calving (OR = 59 d, 95% CI = 20, 96, and OR = 74 d, 95% CI: 37, 109). Compared with type I cows, statistically significant milk production losses during the initial 305 DIM of 199 and 335 kg were estimated in type II and III cows, respectively. This difference was due to a greater rate of production decline (less persistence) after peak yield.

No differences in monthly fat and protein percentages or somatic cell counts were observed between the heifer types. Given the long-term effects of DD on health, reproduction, and production, one of the priorities during the rearing period of dairy heifers should be efficient DD prevention and control programs. Such intensive intervention programs based on active long-term DD surveillance, mitigation of risk factors, and prompt treatment are expected to increase overall animal well-being and farm profitability by minimizing the effect of DD during the first lactation.

Key words: heifer, dairy cattle, milk production

INTRODUCTION

Negative well-being and economic consequences due to digital dermatitis (DD) and the indirect environmental impact of chemicals used for its prevention are commonplace in confined cattle production systems (Bergsten, 2001; Refaai et al., 2013; Sullivan et al., 2013). Traditional prevention and control programs, based on topical treatment of lame cows affected with DD and herd-level use of disinfectant footbath solutions, have limited success (Relun et al., 2013a). Part of the failure to control the DD problem is associated with control programs that are focused primarily on the adult cattle population, whereas heifers during the rearing period do not receive enough care regarding prevention and control of DD. Research indicates that cattle can become infected at a young age, with important implications for the epidemiology of DD (Laven and Logue, 2007; Holzhauer et al., 2012). However, DD problems of youngstock are often overlooked as these animals are handled less frequently, DD cases are easily missed (Frankena et al., 2009), and youngstock facilities are often not suitable for the implementation of appropriate control programs. In addition, the long-term effect of DD has not been investigated extensively (Holzhauer et al., 2012; Gomez et al., 2013), and it is widely believed that intensive use of footbathing and topical treatment of lesions after the first calving are sufficient to solve the potential consequences of pre-calving DD infections.

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Research supports the negative associations of DD on health, milk production, and reproductive performance during the first lactation. Cha et al. (2010) calculated that the cost of DD ranged between \$3 and \$239 during the first lactation, depending on the level of milk yield for each individual animal. Hernandez (2001) found decreased reproductive performance in cows affected with DD. Without focusing specifically on DD, the negative effect of lameness on different aspects of cow health, including nutrition, BCS, or culling have been reviewed in the literature (Huxley, 2013). However, there is still a gap in the literature as to the effect of DD events during rearing period on first-lactation performance of affected animals.

Our hypothesis was that single or repeated DD events occurring between breeding and first calving could undermine the future performance of affected animals, particularly during first lactation. Thus, this study aimed at using indicators such as fresh cow health, reproductive and hoof health outcomes, and milk production to describe and quantify the effect of parturient DD on first-lactation performance.

MATERIALS AND METHODS

The study was approved by the School of Veterinary Medicine Animal Care and Use Committee under Protocol N. V-1525 issued by the Research Animal Resources Center of the University of Wisconsin-Madison.

Heifer Study Period

A cohort of 719 pregnant heifers was enrolled between August 2011 and October 2012 at a mean (SD) age of 17.8 (1.6) mo in a commercial Holstein dairy operation endemically infected with DD. The heifers were part of a different randomized controlled study in which the animals were allocated to 1 of 2 groups and followed for a period of 6 mo (interquartile range = 5.4–6.2 mo). The aim of this study was to evaluate the effect of an organic trace mineral premix for preventing DD lesions during the rearing period and to quantify the effect of precalving DD on first-lactation heifers. Both groups received the same base TMR (Table 1). One of the groups was fed with a standard inorganic trace mineral premix (**STD**), and a second group was fed with an organic trace mineral premix (**HOTMI**; Zinpro Performance Minerals, Eden Prairie, MN). At 252 (± 7) d into the first pregnancy, both heifer groups were moved to a prefresh group, joining the adult cows until calving. During the follow-up period, the rear feet of each heifer were inspected in a stand-up chute (M-Series; Comfort Hoof Care Inc., Baraboo, WI) at enrollment, 3 mo later, and on the last day of follow-

Table 1. Description of TMR (% of DM unless otherwise noted) offered during the rearing (80 d pregnant to 3 wk prepartum), fresh (2.5 ± 1 wk after calving), and postfresh (remaining first lactation) periods

Component	Rearing	Fresh	Postfresh
DM (%)	56.6	47	46
Forage DM	52.1	55	54.7
CP	14.6	16.9	16
NDF	53.7	30.4	30.8
ADF	36.1	19.7	18.7
NE _L (Mcal/kg)	1.23	0.74	0.77
Ether extract	2.80	4.9	5.3
NFC	24.5	41	42.2
Calcium	0.77	0.92	0.88
Phosphorus	0.31	0.38	0.37
Potassium	2.00	1.6	1.29
Magnesium	0.24	0.37	0.35
Chlorine	0.42	0.48	0.5
Sulfur	0.21	0.2	0.2

up (about 6 mo into the study period). On detection of a clinical DD lesion, 15 mL of dry tetracycline-HCl powder (Tet-Sol 324; Alpharma Inc., Fort Lee, NJ) was applied under a light wrap and the wrap was removed between 24 and 48 h later. Weekly evaluations (up to 7 evaluations) were done in heifers affected with DD until clinical cure. As part of a separate study, functional hoof trimming was randomly implemented in 53% of the heifers before first calving.

Immediately before calving, all heifers in the study were classified on the basis of the number of active DD lesions identified during the rearing period. Active DD lesions were defined, following Döpfer et al. (1997), as an ulcerative DD lesion with a diameter ≥ 20 mm (M2). Heifers were classified as type I (no active DD lesions identified), type II (only one active DD lesion identified), or type III (multiple active DD lesions identified during the follow-up period).

First-Lactation Study Period

All heifers calved between December 2011 and November 2012, and data from their first lactation was collected until heifers were dried-off (end of first lactation), heifers left the herd, or the study was terminated in March 2014. A minimum lactation period of 305 DIM was recorded for all animals not leaving the herd by March 2014.

During the first-lactation period, 2 different TMR were delivered. All animals were fed a TMR during the fresh period (2.5 ± 1 wk) and a second TMR (post-fresh) during the remaining lactation period (Table 1). The TMR, formulated for an average production per cow per day of 43 kg, was delivered twice a day, year round. The animals were housed in naturally ventilated barns with freestalls bedded with recycled sand, and

were milked 3 times a day. Stocking density relative to stalls was kept at $\leq 80\%$ during the fresh period and between 100 and 110% between the fresh period and dry-off.

Demographic Characteristics and Body Measurements

Age and days of pregnancy (days carrying calf; **DCC**) were obtained from the on-farm software (DC305, Valley Agricultural Software, Tulare, CA; Table 2). Individual hip height and heart-girth circumference were measured at 3 wk prepartum, with each heifer standing up in the chute, and before any of the legs were attached for inspection. Hip height was measured using a measuring stick (Nasco, Fort Atkinson, WI) placed in between the iliac crests, and heart-girth circumference was measured using a tape measure (Weight-By-Breed Dairy Management Tape, Nasco) around the chest, fitted snugly behind the front legs and shoulder blades. Locomotion scores (**LMS**) were measured 3 wk before calving in an increasing scale from 1 to 5 in 1-point increments (where 1 = not lame cow; Sprecher et al., 1997). The locomotion score was dichotomized for analysis purposes into non-lame (score of 1 or 2) and lame (score of >2).

Fresh Cow Health, and Reproductive and Lameness Parameters

Health and reproductive events were obtained from the on-farm software (DC305, Valley Agricultural Software). The farm definition of the different health events considered in the study was as follows: calving assistance was defined on a scale from 0 to 3, where 0 = a calving with no calving assistance, and scores 1 to 3 were assigned when a manual check was provided in a calving in progress, active manual assistance was provided from the beginning of delivery, and the use of mechanical (obstetric chains or calf-jack) was needed, respectively. The number of calves born dead was also recorded (stillbirths).

During a period of 2.5 ± 1 wk after calving, all fresh cows were checked daily for the presence of any health abnormality or low milk production. Retained fetal membranes was defined as fetal membranes being retained for more than 24 h after calving. Uterine infection was defined when any abnormal uterine discharge was detected on inspection. Ketosis was diagnosed if a cow was identified off feed, with low milk production and a positive KetoCheck test (Ceva Animal Health, Lenexa, KS). Mastitis was checked 3 times a day in the milking parlor and defined as the presence of abnormal milk in at least one quarter. Respiratory disease was defined as presence of high fever ($>39.5^{\circ}\text{C}$), difficulty breathing, or cough and abnormal lung sounds. Culling for health reasons (dead or sold) during the initial 60 d after calving was also considered a health performance indicator (Dechow and Goodling, 2008).

All cows were subjected to the same reproductive program schedule for the first insemination. Timed artificial insemination (**TAI**) based on a Double-Ovsynch synchronization program as described in Souza et al. (2008) was performed in $>99\%$ of the first-lactation animals present on the farm after 50 DIM. The parameters used to evaluate the reproductive performance in this study were the conception rate at first TAI (**CR**), the mean number of days open (**DOPN**, defined as days from calving to conception), and the percentage of cows marked as “reproductive failure” (present in the farm but removed from the reproductive program).

Routine trimming was scheduled between 100 and 150 DIM and at dry-off. A professional trimming service visited the farm weekly and an in-house trimmer performed daily hoof trimming on selected animals as needed. All trimming events were recorded chute-side using a commercial software program (Accu-Trim Hoof Analyzer, Comfort Hoof Care Inc.). All trimmers received 2 training sessions for data entry in Accu-Trim by the first author (AG) and were visited monthly to ensure the recording accuracy. Events recorded in the trimming software were further summarized as DD (DD lesion receiving topical treatment), other infectious lesions (foot-rot and corn), and noninfectious le-

Table 2. Characteristics (mean; SD in parentheses) observed at enrollment by type of heifer

Characteristic	Heifer type ¹		
	Type I	Type II	Type III
No. of heifers (%)	458 (63.7)	136 (18.9)	125 (17.4)
Age (mo)	17.7 (1.7)	17.9 (1.8)	18.1 (1.5)
Girth circumference (cm)	197 (7.7)	199 (7.4)	199 (7.9)
Hip height (cm)	144 (3.7)	144 (3.5)	145 (3.4)

¹Type I = no digital dermatitis (DD) cases diagnosed before calving; type II = 1 DD case diagnosed before calving; type III = 2 or more DD cases diagnosed before calving.

sions. The noninfectious lesions included in the analysis were white line disease, sole hemorrhage, white line hemorrhage, sole fracture, sole ulcer, toe ulcer, rotated claw, and thin sole. Only the first noninfectious lesions were included in the final data set. A 3-times-per-week footbath (Monday, Tuesday, Wednesday) for the lactating herd was performed during the study, using a 3-wk rotating schedule of 5% copper sulfate, 1% lincomycin (Lincomix 20, Zoetis, Florham Park, NJ), and 5% sodium hypochlorite.

Milk Production and Milk Quality

Daily milk production was recorded during the first lactation of all heifers in the study, and the initial 305 d were considered for the analysis. Percentage fat and protein and log SCC score (**LGSCC**) values were obtained monthly from AgSource Cooperative Services DHI (Verona, WI), and only the 10 initial tests after calving were used for statistical analysis. Ordered monthly tests were included in the models as a categorical variable, using the first test as a reference category. All cows received recombinant bST (Posilac, Elanco Animal Health, Greenfield, IN) every 14 d starting at 57 ± 2 d postpartum until 14 d before dry-off.

Statistical Analysis

Differences in fresh cow health and reproductive and lameness performance between type I and type II or type III cows and heifers were evaluated using logistic or linear regression for binary and continuous outcomes, respectively. All models were adjusted for differences in height, girth circumference, and age at enrollment, in addition to the type of trace mineral supplement (HOTMI or STD) administered before first calving. Interaction terms between types I, II, and III and prepartum mineral supplement were also evaluated. For linear models, diagnostic plots were used to evaluate potential violations of linearity, constant variance or normality. Goodness-of-fit was evaluated using adjusted R^2 and Akaike information criterion, and deviance tests for linear and logistic models respectively. The general model equation was

$$Y = \beta_0 + \beta_1 \text{ Heifer type}_i \times \beta_2 \text{ Supplement group}_i \\ + \beta_3 \text{ Height}_i + \beta_4 \text{ Girth circumference}_i \\ + \beta_5 \text{ Age}_i + e_i, \quad [1]$$

where Y = assisted calving (score 1 vs. score >1), stillbirths [yes or no (Y/N)], culling <60 DIM (Y/N), fresh cow disease (0 vs. at least 1 present), reproductive failure (Y/N), conception at first service (pregnant

Y/N), trimming during the first lactation (Y/N), presence of a noninfectious lesion (Y/N), or a DD event during the first lactation (Y/N) were considered as dichotomous outcomes. Days in milk at first service, days open, and DIM at first DD event represented the continuous outcomes considered; β_0 = intercept of the models, where the type I group was considered to be the reference group; β_1 *Heifer type* = estimate of the difference between type I and type II heifers or between type I and type III heifers according to the number of DD events diagnosed between enrollment and first calving; β_2 *Supplement group* = estimate of the difference between heifers fed HOTMI or STD minerals during the prepartum period using the STD group as reference; β_3 , β_4 , and β_5 = adjustments of the independent effects of age, height, and girth circumference at enrollment between the different heifer types.

Milk production (**MP**) was evaluated using linear regression in 2 steps. During the first-step regression (**FSR**), each individual lactation curve was modeled using an adaptation of the exponential model described by Wilmink (1987). In Wilmink (1987), the daily milk production (DMY) was modeled as follows:

$$\text{DMY} \sim a + b \exp(\text{WF} \times \text{DIM}) + c \text{DIM}, \quad [2]$$

where a was associated with the level of production, b with production increase toward peak yield, c with production decrease after peak yield, and the Wilmink factor (**WF** = -0.05) with the moment of peak yield. Wilmink (1987) assumed the same moment of peak for all animals around 50 d postpartum. In the present analysis, a lactation curve was calculated for each cow to account for individual differences in the timing of peak yield. To detect the maximum milk production period, peak yield was defined as the maximum rolling 5-d average daily milk production between 80 and 125 d after calving. The 5-d rolling average was chosen to reduce variation in daily milk yield data. The WF parameters were estimated for each individual animal after calculating the specific DIM at peak yield. Only cows with at least 80 DIM were included in the analysis. A new data set containing the estimates of a , b , c , and WF was then compiled from the FSR (data are summarized in Table 6). In the second-step regression, multivariable linear regressions to predict b , c , and WF were performed following Equation [1]. The models were also adjusted for the level of production (parameter a in Eq. [2]) as recommended by Bicalho et al. (2008) and weighted by the inverse of the variance of each individual model (Guthrie et al., 2014). The regression of the rate of increase toward peak milk (parameter b in Eq. [2]) was further adjusted for the occurrence of a DD event before 151 DIM (DDEarly)

Table 3. Differences in locomotion score, calving outcomes, and fresh cow diseases between heifers of type I and heifers of type II or III

Characteristic	Heifer type ¹			Adj. OR ² (95% CI) Type II	Adj. OR ³ (95% CI) Type III
	Type I (n = 458)	Type II (n = 136)	Type III (n = 125)		
Locomotion score ⁴ >2, no. (%)	2 (0.5)	3 (2.6)	8 (8.1)	4.5 (0.72, 34)	13.5*** (3.0, 93)
Assisted calving score ⁵ >0, no. (%)	270 (59.0)	83 (61.5)	87 (69.6)	1.04 (0.69, 1.58)	1.33 (0.85, 2.10)
Stillbirths, ⁶ no. (%)	53 (11.6)	15 (11.0)	17 (13.6)	0.99 (0.51, 1.8)	1.07 (0.55, 1.97)
Culling <60 DIM, ⁷ no. (%)	35 (7.6)	11 (8.1)	12 (9.6)	1.05 (0.5, 2.09)	1.06 (0.48, 2.18)
Fresh cow disease <60 DIM, ⁸ no. (%)					
Healthy ⁹	281 (61.3)	77 (56.6)	71 (56.8)	0.83 (0.55, 1.24)	0.82 (0.54, 1.27)
Displaced abomasum	29 (6.3)	4 (2.9)	8 (6.4)	—	—
Uterus infection	40 (8.7)	13 (9.6)	7 (5.6)	—	—
Ketosis	7 (1.5)	0 (0)	4 (3.2)	—	—
Mastitis	103 (22.5)	37 (27.2)	38 (30.4)	—	—
Respiratory disease	18 (3.9)	8 (5.9)	9 (7.2)	—	—
Retained fetal membranes	36 (7.9)	10 (7.4)	7 (5.6)	—	—

¹Type I = no digital dermatitis (DD) cases diagnosed before calving; type II = 1 DD case diagnosed before calving; type III = 2 or more DD cases diagnosed before calving.

²Odds ratio adjusted for age, height, and girth circumference at enrollment between type I and type II.

³Odds ratio adjusted for age, height, and girth circumference at enrollment between type I and type III.

⁴Locomotion score based on a scale from 1 to 5.

⁵Assisted calving score based on a scale from 0 to 3.

⁶Calves born dead at calving.

⁷Cows died or sold before 60 DIM (sales for dairy not included).

⁸Cows presenting one of the listed fresh cow diseases during the period <60 DIM.

⁹Cows not diagnosed with any disease during the period <60 DIM.

*** $P < 0.01$.

to account for potential confounding effects of early DD on milk production. Similarly, the regression of the rate of decrease after peak milk (parameter c in Eq. [2]) was adjusted for the occurrence of DDEarly in addition to correction for the reproductive status including DOPN in the model. Model assumptions and goodness-of-fit were assessed as described for the previous models.

Differences in milk quality traits, including fat and protein percentages and LGSCC, between heifer types were also evaluated using Equation [1], additionally including the month of evaluation as a categorical fixed effect in the model and a random term to account for the repeated individual observations. The error level was established at $\alpha = 0.05$, and all analyses were performed using R statistical software version 3.1.0 (R Core Team, 2013).

RESULTS

The results for first-lactation performance in relation to prepartum DD are presented for fresh cow health, reproduction and lameness, and milk production and milk quality.

Fresh Cow Health, Reproduction, and Lameness

Although the percentages of heifers receiving calving assistance, stillbirths, culled before 60 DIM, and diag-

nosed with at least one fresh cow disease were higher in type II and type III than in type I cows, none of those differences were statistically significant after adjusting for age, height, and girth circumference and the trace mineral supplement received during the rearing period (Table 3).

Significant differences were found in reproductive performance between type II and III cows and type I cows. Given the use of TAI for the first service, an expected similar number of days at first insemination was found between the different types. However, absolute reductions in CR of 6 and 13.3% were observed, respectively, in type II and III heifers in relation to type I heifers. Those differences corresponded to a relative pregnancy odds ratio (OR) of 0.82 (95% CI: 0.52, 1.26) in type II heifers, and a statistically significant pregnancy OR of 0.55 (95% CI: 0.33, 0.89) in type III heifers (Table 4) when compared with type I heifers. In addition, type III heifers were associated with significantly more days from calving to conception (OR = 2,495% CI: 5.2, 43) compared with type I heifers. Slightly higher percentages of type II and III animals were removed from the reproductive program but this difference was not significant (Table 4).

Three weeks prepartum, a mild level of lameness was observed in all types of heifers. Only 2 (0.5%) type I, 3 (2.6%) type II, and 8 (8.1%) type III heifers presented

Table 4. Differences in reproductive performance outcomes between heifers of type I and heifers of type II or III

Characteristic	Heifer type ¹			Diff-OR ² (95% CI) Type II	Diff-OR ³ (95% CI) Type III
	Type I (n = 413)	Type II (n = 121)	Type III (n = 112)		
DIM at first service, mean (SD)	80.7 (2.43)	81.1 (6.0)	81.4 (1.8)	0.4 (−0.27, 1.08)	0.7 (0.01, 1.39)
Conception at first service, no. (%)	175 (42.3)	44 (36.3)	33 (29.0)	0.82 (0.52, 1.26)	0.55** (0.33, 0.89)
DOPN, ⁴ mean (SD)	132 (73)	134 (73)	157 (90)	0.46 (−16, 17)	24** (5.2, 43)
Cows marked as reproductive failure, ⁵ no. (%)	47 (10.3)	18 (13.2)	16 (12.8)	1.22 (0.64, 2.23)	1.33 (0.69, 2.45)

¹Type I = no digital dermatitis (DD) cases diagnosed before calving; type II = 1 DD case diagnosed before calving; type III = 2 or more DD cases diagnosed before calving.

²Odds ratio adjusted for age, height, and girth circumference at enrollment between type I and type II.

³Odds ratio adjusted for age, height, and girth circumference at enrollment between type I and type III.

⁴DOPN = days from calving to conception.

⁵Cows removed from the reproductive program during the first lactation.

** $P < 0.05$.

LMS >3 and none of them were diagnosed with an LMS = 5. However, the difference between type I and type III heifers was statistically significant ($P < 0.01$; Table 3). Of all the animals calved, 90% were trimmed at least once during the lactation. In the trimming chute, the presence of a noninfectious hoof lesion was more common in type III animals (36.9%) than in type I and type II animals (28.3 and 25.6%, respectively), but this difference was not significant (Table 5). In contrast, occurrence of DD during first lactation did differ significantly ($P < 0.01$) between type II or type III heifers and type I heifers (Table 5). A greater percentage of type II and III heifers were diagnosed with at least one DD event during first lactation than type I heifers (45.6 and 67.6% vs. 13.7%, respectively; Figure 1). Similarly, the total number of DD events diagnosed per first-lactation heifer was higher in type II and III cows. In addition, DD lesions were identified significantly sooner after calving in type II and III cows compared with healthy cows (OR = 59, 95% CI: 96, 20 d; and OR = 74, 95% CI: 109, 37 d sooner, respectively).

Milk Production and Milk Quality

The results of the evaluation of MP by heifer type are shown in Tables 6 and 7. Table 6 shows a summary of parameter means and standard errors obtained from the FSR. In Table 6, adjusted estimates of the milk lactation curve parameters are shown. The slope of the production increase toward peak yield (parameter b) was shown to be statistically significantly larger in type II and III [1.49 (SE 0.63) and 1.80 (SE 0.67), respectively], indicating that before first-lactation heifers reached peak yield, a higher MP was observed in these animals. On the other hand, a significantly higher rate of MP decrease (parameter c) was shown after peak yield in type II and III [−0.0048 (SE 0.0027) and

−0.0078 (SE 0.0030), respectively] compared with the type I group. The level of production in relation to parameter b and both the level of production and the type of trace mineral nutrition during the rearing period in relation to parameter c showed a significant association with the MP curve. As expected, the WF analysis did not show any significant differences between the types.

The predicted milk production (95% CI) over 305 d was 12,464 (8,892, 16,060), 12,265 (8,427, 16,132), and 12,129 (8,252, 16,073) kg, respectively, for type I, II, and III animals fed the HOTMI premix during the rearing period (Figure 2). Similarly, 305-d MP was significantly reduced for type I, II, and III animals fed the STD premix: 12,272 (8,780, 16,073), 12,074 (8,314, 16,146), and 11,938 (8,139, 16,049) kg, respectively. No significant differences in milk fat and protein percentages or LGSCC were found between the different heifer types (Figure 3).

DISCUSSION

Overall, animals experiencing at least one DD event between breeding age and first calving had decreased first-lactation performance and fertility compared with animals never diagnosed with DD during the same period. Moreover, first-lactation performance and fertility were further negatively affected if animals experienced multiple DD events during rearing.

Fresh Cow Health, Reproduction, and Lameness

Three weeks prepartum, type III heifers showed a significantly higher risk of being lame (adjusted OR = 13.5, 95% CI: 3, 93) than type I heifers. The number of assisted calvings and stillbirths, the presence of disease between calving and 60 DIM, and total culling during the same period were increased in animals ex-

Figure 1. Percentage and number of cows and digital dermatitis (DD) events recorded during first lactation in cows not diagnosed with DD during the rearing period (type I), diagnosed with 1 DD event (type II) and diagnosed with multiple DD events (type III).

Table 5. Differences in hoof health outcomes between heifers of type I and heifers of type II or III

Characteristic	Heifer type ¹			Adj. OR ² (95% CI) Type II	Adj. OR ³ (95% CI) Type III
	Type I (n = 458)	Type II (n = 136)	Type III (n = 125)		
Trimmed during first lactation, ⁴ no. (%)	417 (91)	125 (92)	111 (89)	1.07 (0.54, 2.26)	0.83 (0.42, 1.74)
Presence of a noninfectious lesion, ⁵ no. (%)					
Healthy	299 (71.7)	93 (74.4)	70 (63.1)	1.36 (0.73, 1.82)	0.83 (0.52, 1.34)
White line disease	43 (10.3)	8 (6.4)	11 (9.9)	—	—
Sole hemorrhage	34 (8.2)	16 (12.8)	10 (9.0)	—	—
White line hemorrhage	12 (2.9)	5 (4.0)	4 (3.6)	—	—
Rotated claw	5 (1.2)	0 (0)	3 (2.7)	—	—
Sole fracture	3 (0.7)	0 (0)	2 (1.8)	—	—
Toe ulcer	11 (2.6)	5 (4.0)	3 (2.7)	—	—
Sole ulcer	4 (1.0)	2 (1.6)	3 (2.7)	—	—
Thin sole	36 (8.6)	8 (6.4)	11 (9.9)	—	—
DD event during first lactation, ⁶ no. (%)	57 (13.7)	57 (45.6)	75 (67.6)	5.16*** (3.23, 8.29)	12.5*** (7.52, 21.1)
No. of DD events, no. (%)					
1	32 (56)	25 (44)	23 (31)	—	—
2	7 (12)	14 (25)	10 (13)	—	—
3+	18 (32)	18 (31)	42 (56)	—	—
DIM at first DD event, mean (SD)	244 (112)	193 (103)	169 (90)	−59*** (−96, −20)	−74*** (−109, −37)

¹Type I = no digital dermatitis (DD) cases diagnosed before calving; type II = 1 DD case diagnosed before calving; type III = 2 or more DD cases diagnosed before calving.

²Odds ratio adjusted for age, height, and girth circumference at enrollment between type I and type II.

³Odds ratio adjusted for age, height, and girth circumference at enrollment between type I and type III.

⁴Cows with at least one inspection or trimming at the trimming chute.

⁵Cows with at least one noninfectious lesion recorded during the first lactation in any foot.

⁶Cows with at least one DD event diagnosed during the first lactation.

*** $P < 0.01$.

Table 6. Mean (SEM) of the parameters obtained from the first-step regression

Parameter	Heifer type ¹		
	Type I (n = 418)	Type II (n = 123)	Type III (n = 112)
Level of production (<i>a</i>)	46.2 (0.35)	47.0 (0.58)	46.7 (0.63)
Production increase toward peak yield (<i>b</i>)	−28.2 (0.42)	−28.0 (0.70)	−27.0 (0.79)
Production decrease after peak yield (<i>c</i>)	−0.029 (0.001)	−0.036 (0.003)	−0.035 (0.003)
Wilmink factor (WF)	−0.042 (0.0003)	−0.043 (0.0006)	−0.044 (0.0007)

¹Type I = no digital dermatitis (DD) cases diagnosed before calving; type II = 1 DD case diagnosed before calving; type III = 2 or more DD cases diagnosed before calving.

periencing DD during the prepartum period. Lameness before calving has been documented as a risk factor for suboptimal performance during the subsequent lactation (Calderon and Cook, 2011; Vergara et al., 2014). Although it was not a statistically significant finding, type III animals tended to experience more adverse health events, such as mastitis and ketosis, immediately postpartum compared with type I animals (Table 3). Calderon and Cook (2014) reported that lameness before calving increases the risk of ketosis, and the risk of mastitis in lame cows can be estimated given the changes in resting behavior (Gomez and Cook, 2010; Navarro et al., 2013). However, pairwise comparisons between disease categories lacked power in the current study.

The association between lameness occurring during lactation and reproductive outcomes has been extensively documented (Sogstad et al., 2006; Katsoulos et al., 2009; Olechnowicz and Jaskowski, 2011). Specifically for DD, Hernandez (2001) reported a hazard ratio for conception of 0.71 and 0.31 in cows exclusively affected with DD and affected with mixed lesions (DD and claw lesions), respectively. However, long-term effects of prepartum DD on reproduction have not previously been reported in the literature. A significant association was observed between conception rate at first TAI and DOPN when comparing type I and III groups. This difference in DOPN was not confounded with variation in time from calving to first insemination, given that >99% of the animals were serviced at a

Table 7. Summary of the models estimating adjusted parameters *b*, *c*, and *d*

Parameter model	Category	Mean	SEM	<i>t</i> -value	<i>P</i> -value
Production increase toward peak yield (<i>b</i>) ¹ Heifer type	Type I	Referent	—	—	—
	Type II	1.49	0.63	2.30	0.02**
	Type III	1.80	0.67	2.40	0.01**
		−0.80	0.04	−18.8	<0.01***
Level of production ² (<i>a</i>) Supplement group ³	Standard trace mineral	Referent	—	—	—
	Organic trace mineral	−0.54	0.49	1.10	0.27
Production decrease after peak yield (<i>c</i>) ⁴ Heifer type	Type I	Referent	—	—	—
	Type II	−0.0048	0.0027	−1.77	0.07*
	Type III	−0.0078	0.0030	−2.53	0.01**
		−0.0019	0.0002	−10.3	<0.01***
Level of production (<i>a</i>) Supplement group	Standard trace mineral	Referent	—	—	—
	Organic trace mineral	0.0043	0.0020	−2.74	<0.03**
Wilmink factor (WF) ⁵ Heifer type	Type I	Referent	—	—	—
	Type II	−0.00007	0.00009	−0.83	0.40
	Type III	0.00002	0.00009	0.16	0.87
		0.000003	0.000006	0.46	0.63
Level of production (<i>a</i>) Supplement group	Standard trace mineral	Referent	—	—	—
	Organic trace mineral	−0.00011	0.0001	1.63	0.10

¹ $b = \beta_0 + \beta_1 \text{Heifer type}_i + \beta_2 \text{Supplement group}_i + \beta_3 \text{Height}_i + \beta_4 \text{Girth circumference}_i + \beta_5 \text{Age}_i + \beta_6 \text{Early DD event}_i + e_i$, where DD = digital dermatitis.

²Level of production = parameter *a* obtained from the first step regression.

³Supplement group = type of prepartum trace mineral supplementation.

⁴ $c = \beta_0 + \beta_1 \text{Heifer type}_i + \beta_2 \text{Supplement group}_i + \beta_3 \text{Height}_i + \beta_4 \text{Girth circumference}_i + \beta_5 \text{Age}_i + \beta_6 \text{Early DD event}_i + \beta_7 \text{DOPN}_i + e_i$, where DOPN = days from calving to conception.

⁵ $\text{WF} = \beta_0 + \beta_1 \text{Heifer type}_i + \beta_2 \text{Supplement group}_i + \beta_3 \text{Height}_i + \beta_4 \text{Girth circumference}_i + \beta_5 \text{Age}_i + \beta_6 \text{Early DD event}_i + e_i$.

* $P < 0.1$, ** $P < 0.05$, *** $P < 0.01$.

Figure 2. Predicted lactation curves (calculated using the second-step regression estimates) during the initial 305 DIM for type I, II, and III heifers by trace mineral premix fed during a 6-mo period before first calving. HOTMI = organic trace mineral premix; STD = standard inorganic mineral premix.

fixed time under the Double-Ovsynch protocol, or with differences in first-lactation animals removed from the reproductive program (Table 4). A reduction of 13.3% in conception rate at first TAI (OR = 0.55, 95% CI: 0.33, 0.89) and an increase in DOPN of 24 d (95% CI = 5.2, 43) can significantly affect the profitability of dairy operations (Giordano et al., 2011; Cabrera, 2014). As an example, using the calculation of economic net return gain published by Cabrera (2014), assuming a constant service rate, a CR difference of 13.3% would correspond to an economic net return gain of \$43 per cow per year.

All noninfectious lesions recorded (with the exception of white line disease) were more frequently associated with type III heifers, and a similar association was found for type II and type I heifers (Table 5). It has previously been hypothesized that DD could predispose to noninfectious hoof lesions, given the changes in hoof conformation due to DD (Gomez et al., 2015), but this association was not found to be statistically significant in the current study. In our data set, the low incidence of lesions may have limited our ability to demonstrate differences in noninfectious hoof lesions between types of heifers. In addition, during the prepartum period,

all DD lesions were promptly treated and re-evaluated until clinical cure was achieved. This probably reduced lesion severity (Leach et al., 2012) and influenced the consequences of DD for the number of noninfectious lesions during lactation.

The relationship between types of heifers and DD incidence observed during the first lactation deserves special attention. Although Holzhauer et al. (2012) did not differentiate animals by the number of DD events diagnosed per animal before first calving, they showed an increased risk of DD (OR = 5.97, 95% CI: 3.1, 11.8) during the first lactation in animals with DD lesions diagnosed during the rearing period. Similarly, in our study, type II and type III heifers showed a statistically significant increase in DD events diagnosed during early lactation compared with type I animals (13.7, 45.6, and 67.7% in types I, II, and III, respectively; Table 5 and Figure 1). In addition to an increased risk of experiencing a DD event during the first lactation, more DD events were recorded earlier in lactation for type III heifers. Any effects of clinical DD on health or production during the first lactation (Relun et al., 2013b) are attributable at least in part to the prepartum DD history. As a consequence, successful prevention and

Figure 3. Mean (SEM) fat and protein percentages and log SCC milk contents for type I, II, and III heifers obtained from the initial 10 DHI tests after calving.

control programs should shift much of their attention to rearing-age heifers with the objective of reducing recurrence rates during the first lactation.

Milk Production and Milk Quality

Huxley (2013) published a review article about the effect of lameness and claw lesions on health and production, highlighting the vast amount of literature demonstrating a negative association. Yeruham (2000) and Pavlenko et al. (2011) reported the effect of DD on production to be 1.8 kg/d of milk over one lactation and 5.5 kg/d for 3 wk post-DD diagnosis, respectively. Specifically for first-lactation heifers, Relun et al. (2013b) reported production losses of 0.50 to 0.63 kg/d depending on the severity of the DD lesions. However, no literature to date has explored the long-term effects of prepartum DD events on postpartum milk production. We have demonstrated how animals experiencing DD during the rearing period produce significantly less milk during their subsequent lactation. The reduced milk production was characterized by a significantly higher rate of production decline after peak yield (Table 7 and Figure 2). The adjusted milk loss prediction during the initial 305 DIM corresponded to reductions of 199 and 335 kg for type II and III animals, respectively, compared with type I cows. Although milk loss during the first lactation can be explained in part by the presence of recurrent DD lesions (Relun et al., 2013b) more likely occurring in cows with a previous history of DD, the models used in the current study evaluating milk production parameters were adjusted for the presence of a DD lesion before 150 DIM. The purpose was to correct for the influence of DD events on milk production around the highest milk-producing portion of the lactation. The same reasoning could be applied to the adjustment of parameter *c* (slope of the decay after peak yield) for differences in DOPN, as pregnancy has been associated with milk production changes (Roche, 2003). The results observed suggest that the negative association of DD with milk production is likely due the continuous discomfort experienced by cows affected with the disease (Whay et al., 1997), in addition to changes in the hoof conformation (Gomez et al., 2015) that might result in significant changes in the cows' behavior (Pavlenko et al., 2011; Navarro et al., 2013).

During the first lactation, all animals in the study were fed the same TMR, whereas different trace mineral supplementation was provided during the rearing period. Gomez et al. (2014) indicated a likely relationship between trace mineral nutrition and the development of acute DD lesions. In addition, organic trace mineral nutrition has been associated with increased milk production (Rabiee et al., 2010). Thus, the type of

trace mineral nutrition (HOTMI vs. STD) was included in the models as a covariate. In this study, we found a significant relationship between the type of nutrition prepartum and milk production (Figure 2), where cows fed with the HOTMI premix produced on average 191 kg more milk during the initial 305 DIM than the group fed the STD mineral supplement. However, no significant interaction between heifer types and prepartum ration type was found.

Further analysis was performed to evaluate possible differences in milk quality (fat, protein, and LGSCC) during the initial 10 DHI tests after calving. In agreement with Pavlenko et al., (2011), no differences in milk fat and protein percentages were found between types of heifer (Figure 3).

One limitation of this study in demonstrating the effect of DD on first-lactation performance is that during the rearing period all DD lesions were promptly treated upon diagnosis, and treatment was repeated at weekly intervals until clinical cure was observed. Compared with common field situations, our surveillance and treatment intensity likely decreased the severity of DD lesions and probably led to an underestimation of milk yield losses. Given that the severity of the lesions depends significantly on the time between disease onset and topical treatment (Gomez et al., 2014), the results might be biased toward zero, with larger differences between animal types expected under standard field conditions. A second limitation of the study was lameness detection during first lactation. As shown in Frankena et al. (2009), lameness symptoms in cows affected with DD depend on severity, and mild cases are easily missed. Digital dermatitis diagnosis was clustered around the scheduled mid-lactation and dry cow trimming, reflecting the low sensitivity of hoof health management programs based on lameness detection to identify hoof lesions. To overcome this lack of precision in DD detection, DD occurrence during the first lactation was simplified to a dichotomous variable indicating whether a cow was diagnosed with DD during the initial 150 DIM or not.

Finally, the study was conducted in a single dairy, a fact that limits its external validity. Although the study farm characteristics are common for a large dairy operations, further research is necessary in different dairy production systems to further validate the results presented.

CONCLUSIONS

Occurrence of DD events during the rearing period significantly affected first-lactation performance. Heifers diagnosed with repeated DD events during the rearing period showed the greatest milk production losses

and suboptimal reproductive outcomes. Given the long-term effects of DD on health, reproduction, and production, and with the aim of successful DD prevention and control programs, attention should shift to the rearing period and be continued during lactation. Intensive intervention programs based on active surveillance and prompt treatment will likely help increase overall animal well-being and farm profitability, and such programs will decrease the burden of disease and workloads associated with the management of cows affected by DD.

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