Heel Erosion and Other Interdigital Disorders in Dairy Cows: Associations with Season, Cow Characteristics, Disease, and Production

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ABSTRACT

Epidemiologic associations between variables obtainable from dairy cow records and the occurrence of heel erosion, interdigital dermatitis, and interdigital hyperplasia at claw trimmings were estimated with multivariable logistic regression analysis on data from 1170 and 542 cows in lactation 1 and lactations 2 to 9, respectively. In the 17 herds, heel erosion, interdigital dermatitis, and hyperplasia occurred among 43.8, 4.5, and .9% of cows in lactation 1 and among 69.1, 7.6 and 5.9% of cows in lactations 2 to 9, respectively. Severity of heel erosion increased with parity, and risk increased with stage of lactation. Strong seasonal effects were present. Various combinations of veterinary treatments were associated with heel erosion and hyperplasia depending on parity, stage of lactation, and the presence of other claw disorders. In contrast, veterinary treatment had a protective effect for interdigital dermatitis in lactations 2 to 9. Severe degrees of sole ulcer increased the risk of heel erosion and interdigital dermatitis. The digital disorders were strongly associated in lactation 1 but not in later lactations. Heel erosion and hyperplasia were highly repeatable from one lactation to another.

(**Key words**: epidemiology, lameness, dairy cattle)

Abbreviation key: CI = confidence interval, LCP = logit cumulative probability, OR = odds ratio.

INTRODUCTION

In the majority of cases, dairy cow lameness originates from the digit. Disorders affecting the sensitive laminae of the digit (sole ulcer and laminitis) are probably the most important causes. Apart from sole ulcer, the most common chronic digital disorders in dairy cattle are heel erosion (erosio ungulae), interdigital dermatitis, and interdigital hyperplasia (1, 5, 7, 8, 9, 14, 15, 18, 20, 25). These disorders, affecting the horn and the digital skin, are strongly interrelated (13, 23, 25).

The purpose of this study was to estimate the direction and magnitude of the epidemiologic associations between the potentially available information about possible risk factors and recordings of heel erosion, interdigital dermatitis, and interdigital hyperplasia in dairy cows. The risk factors examined were season of year (at recording and calving), stage of lactation, parity, milk yield, body weight, and health status (both in general and with respect to digital health). Such estimates are expected to be important for problem solving (e.g., pointing out high risk categories of cows), monitoring (e.g., removing sources of error from monitoring variables) in a herd, and for making decisions about individual animals (e.g., culling).

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MATERIALS AND METHODS

Data

Data were from 17 Danish herds (average size ± SD = 88 ± 22). Housing and management systems are described elsewhere (4, 10, 11, 20). All herds were kept in loose housing systems with either solid floor and scraper or slated floor. Six of the herds had access to pasture or exercise lots during one or more summer seasons during the study period. Heel erosion (erosio ungulae) and sole ulcer (pododermatitis circumscripta) were recorded as described previously (4). The interdigital skin of each foot was examined for interdigital dermatitis. The following categories were recorded: degree 1, edema and slight exudation; degree 2, slight fibrous thickening with massive smelling exudation; degree 3, massive fibrous thickening including dorsal part of the interdigital skin; and, degree 4, as in degree 3 with pododerm exposed.

The interdigital skin of each foot was similarly examined for interdigital hyperplasia. Three categories were recorded: category 0, no marked hyperplasia; category a, symmetric hyperplasia; and category b, asymmetric hyperplasia.

Statistical Analysis

To provide odds ratios (OR), which were the epidemiological measure of interest, the data were analyzed with a multivariable logistic regression technique, and the statistical analysis was performed in four stages: 1) data editing, 2) data reduction, 3) model selection, and 4) estimation of effect as described previously (4).

Data Editing

The cows were assigned a score for heel erosion and dermatitis equal to the highest degree of lesion recorded in any foot. Categories a and b of hyperplasia were combined. To examine the effect of digital health status on erosion, dermatitis, and hyperplasia (dependent variables), the cows were assigned different values of the variables for erosion predictor (predictor = independent variable), dermatitis, hyperplasia, and ulcer predictors. When erosion was the dependent variable, variables for prediction of the effect of dermatitis, hyperplasia, and ulcer were assigned a score value indicating the degree of interdigital dermatitis, hyperplasia, and sole ulcer, respectively, recorded for the foot with the highest degree of heel erosion. When dermatitis was the dependent variable, variables for prediction of the effect of erosion, hyperplasia, and ulcer were assigned values similarly. If the values for either erosion, dermatitis, or hyperplasia (dependent variables) were zero, the corresponding (digital) predictor variables were assigned the degree of lesion recorded on the left hind foot. All independent variables were analyzed as categorical variables. The variable for parity was combined into four classes because the data set contained only 124 observations from lactations 4 to 9.

Data Reduction, Model Selection, and Effect Estimation

These stages were performed as previously described (4). For model selection, a 5 to 10% α level for the likelihood ratio test was chosen. The 10% level corresponded to the smallest sample size.

RESULTS AND DISCUSSION

Parity is regarded as an important risk factor for digital disorders. Cows in the first lactation experience conditions before and near calving that differ markedly from conditions experienced by older cows. In consequence, these two groups were analyzed separately for each digital disorder for a total of six different statistical analyses. Tables 1 to 7 give descriptions of the selected variables, percentage distribution of observations by degree of the dependent variables, percentage distribution of observations by estimated effect, effect estimates (OR), and the 95% confidence intervals (CI) of the OR. These analyses will be discussed separately.

Heel Erosion in Lactation 1

The effect estimates presented in Table 1 were derived from a complex final model of erosion in lactation 1 including the terms: season of trimming, season of calving, stage of lactation, FCM, disease, ulcer, combined dermatitis and hyperplasia predictors, season of trimming × season of calving, season of calving

× disease, stage of lactation × sole ulcer, and sole ulcer × combined dermatitis and hyperplasia predictors. Effects of the possible combinations of variables that included more than one product terms were estimated separately. Such a breakdown of data inevitably results in small frequencies of some combinations. Consequently, the effect estimates were imprecise and are not presented in the tables if based on less than approximately 5% of observations. The direction of the effect estimates, however, provided useful information about possible trends when combined with the information from other combinations. The keeping of these small frequency terms in the models made the effect estimates of the other terms more valid and easier to interpret.

Claw trimming in July to December for nondiseased cows that calved in March to October was associated with a 2.4 (OR calculated as 3.1/1.3) times higher risk of erosion compared with nondiseased cows that calved in March to October but were trimmed in January to June. For nondiseased cows, calving in November to February and trimming in July to December were not risk factors (OR = .6/1.0). Calving in March to October was a risk factor for nondiseased cows being trimmed in July to December (OR = 5.2 = 3.1/0.6). For cows being trimmed in January to June, the corresponding OR was 1.3. Moist claw environment combined with manure exposure is regarded as the major determinant of heel erosion (5, 13, 23, 25). The current finding supports this view, because housing and pasture conditions usually were wetter during the fall months when the feeding also was more unstable (e.g., feeding with sugar beets, fresh sugar beet leaves, and wet new grass). The bacterial and chemical (ammonia) degradation of the heel horn is also likely to have been promoted by the warmer conditions during summer. However, the ammonia concentration was only found to be higher in some of the barns (11). The strong

TABLE 1. Final logistic regression model of heel erosion in lactation 1. Heel erosion of the degrees 1, 2, and 3 to 4 occurred among 20.3, 11.4, and 2.1% of the 1170 cows.

Description of variables[1]	Percentage of cows	Odds ratio	95% CI[2]
Month of trimming and month of calving and disease[3]			
Trimming, July–December; calving, March–October; and no disease or other diseases	46.2	3.1	2.1–4.8
Trimming, July–December; calving, November–February; and no disease or other diseases	6.3	.6	.3–1.3
Trimming, January–June; calving March–October; and no disease or other diseases	15.3	1.3	.7–2.2
Trimming, January–June; calving November–February; and no disease or other diseases	28.9	1.0	. . .
Stage of lactation and interdigital lesion and sole ulcer			
Trimming, ≥ 32 DIM;[4] sole ulcer degrees 1–5; and no interdigital lesions	21.8	3.1	2.0–5.0
Trimming, < 32 DIM; sole ulcer degrees 1–5; and no interdigital lesions	3.5	3.4	1.5–7.7
Trimming, ≥ 32 DIM; no sole ulcer; and no interdigital lesions	46.8	2.9	2.0–4.4
Trimming, < 32 DIM; no sole ulcer; and no interdigital lesions	24.6	1.0	. . .
Milk production			
FCM ≥ 19.2 kg[5] (mean ± SD = 21.5 ± 2.4 kg)	42.8	1.5	1.2–2.0
FCM < 19.2 kg (mean ± SD = 16.1 ± 2.4 kg)	57.2	1.0	. . .

[1]In addition, herd-year of calving is included in the model. The four combinations involving disease and the four combinations involving interdigital lesions omitted from the table due to imprecision.

[2]Confidence interval.

[3]Includes combinations of digit, limb, severe, or other.

[4]DIM ≥ 32, mean ± SD = 86 ± 50 d; DIM < 32, mean ± SD = 17 ± 9 d.

[5]FCM = Mean daily 4% FCM during first 100 DIM, in kilograms.

effect of trimming season on cows calving in March to October could be due to poor horn quality among this group of cows, caused by the very labile environmental conditions during the peripartum period, which is regarded as essential with respect to horn production. Conditions during pregnancy might also have played a role, although Thysen et al. (21) did not find significant effects of the housing or pasture conditions (wet, dry, and floor type) during pregnancy. The well known strong protective or curative effect of pasture feeding on heel erosion (7, 13) should have been partially accounted for by the inclusion of the term herd-year of calving in the models. Also, in other studies, seasonal effects are revealed (16, 19, 26). Detailed information of the management conditions in the different studies is necessary for comparison with the present study.

Prior treatment for more complex cases of disease (in this model defined as the classes severe + limb, severe + digit, severe + other, limb + digit, limb + other, digit + other, and disease 3+) occurred among 3.3% of the cows and was strongly positively associated with erosion. The OR ranged from 4.6 to 14.6 but were rather imprecise (not shown). In conclusion, disease and heel erosion clearly occur among the same cows.

Trimming 32 d DIM or greater was associated with a 2.9 times higher risk of erosion among cows without sole ulcer and interdigital dermatitis or hyperplasia. This effect of stage of lactation probably just reflects the amount of time the cows had been exposed to the floor or bedding environment in the barns. The logit cumulative probability (LCP) curves (6) also revealed that the risk remained largely constant after 31 DIM. Among cows with sole ulcer, no effect of stage of lactation was found (an OR = .9 calculated as 3.1/3.4), and sole ulcer per se had an effect only before 32 DIM (OR = 3.4). The previous analysis of these data of the effect of heel erosion on sole ulcer (4) and the review of the literature indicated that sole ulcers cause heel erosion. The present analysis does not support this hypothesis. The rationale behind the hypothesis of heel erosion as a cause of sole ulcer is a reduction of the weight bearing surface of the sole (24), thus increasing pressure on the central sole. The severe cases of heel erosion necessary to produce such a change in weight distribution are unlikely to have occurred early in lactation. In contrast, the alternative hypothesis (25), that sole ulcer softens the claw horn and makes it more easily degradable, is supported by these associations. However, both causal mechanisms are probably in effect since the LCP-curves (not shown), although bivariate, show a more marked effect of sole ulcer degrees 3 to 5 compared with the less severe cases and a stronger effect on heel erosion degrees 3 to 4 (this also indicates a less valid ordinality assumption).

Interdigital dermatitis and hyperplasia were combined in the analysis of lactation 1 cows. Although the frequency of this combined interdigital lesion was low (3.3%), which agrees with Anderson and Lundstrom (1), interdigital lesion was strongly associated with erosion (OR 6.2 to 9.4). The estimates (not shown) also indicated a potentiating effect of sole ulcer or vice versa. The LCP curves were not parallel, indicating a violation of the ordinality assumption. Also, no cases of erosion degrees 3 to 4 occurred among cows with dermatitis predictor degrees 2 to 4. These findings give some support to the hypothesis (13, 24) that heel erosion and interdigital dermatitis are two manifestations of the same disease (with *Bacteroides nodosus* as an important causal component). Nielsen and Smedegaard (9) found a very strong (bivariate) association between heel erosion and interdigital dermatitis and, in addition, stronger association with increasing severity of the disorders.

High daily milk yield (Table 1) was associated with a 1.5 time higher risk of erosion. Likely explanations are: 1) the claws of higher yielding cows were more exposed to manure due to feces consistence, 2) the higher feed intake associated with higher yield forced the cows to spend more time standing while eating, and 3) the horn production might have been impaired by the stress of high production. The above hypotheses could also to some extent be applied to body weight, but no direct or indirect (via milk yield) effect of this factor was found. The LCP-curves showed a slight violation of the ordinality assumptions for FCM and BW.

Heel Erosion in Lactations 2 to 9

The final model of erosion in lactations 2 to 9 included numerous interaction terms making interpretation of the effect estimates impossible.

To enable interpretation, parity 2 cows were analyzed separately from those with parities 3 to 9. The convergence of the LCP curves was an additional argument for these separate analyses. In the first step of the data analysis (before including interaction terms), parity 3 and 4 to 9 were associated with 1.7 (95% CI 1.0 to 2.8) and 3.6 (95% CI 1.9 to 5.9), respectively, times higher risk compared with lactation 2. Comparing this with the frequency of erosion in lactation 1 (Table 1), it can be concluded that the risk of heel erosion increased steadily, as expected (1, 20), from parity 1 through 4 to 9.

The effect estimates for erosion in parity 2 are presented in Table 2. The ordinality assumption was clearly violated with respect to the month of trimming variable because a relatively much higher proportion of severe cases of erosion occurred in July to August. Despite the fact that only 3.5% of the observations were recorded in July to August, the variable could not be removed from the model without increasing the deviance significantly. The effect might be an artefact, but conditions specific for the summer season as mentioned above could have been causal.

The effect of season of calving was very much stronger than in lactation 1. The explanations given above for March to October as a high risk period for lactation 1 cows are also valid for lactation 2, but the huge difference is difficult to explain satisfactorily. A long-term effect of housing might be one explanation. The effect of stage of lactation was more pronounced than in lactation 1, which could be caused by a curative effect of the usually less moist conditions during the first dry period compared with the conditions before first calving.

Severe cases of ulcer tended to be associated with an increased risk of erosion. The effect was, however, modified by the intervals between current and previous claw trimming (the product term ulcer × trim interval was statistically significant). This effect of trimming intervals is more difficult to explain. In the previous

TABLE 2. Final logistic regression model of heel erosion in lactation 2. Heel erosion of the degree 1 and degrees 2 to 4 occurred among 40.6, and 24.7% of the 283 cows.

Description of variables[1]	Percentage of cows	Odds ratio	95% CI[2]
Month of trimming			
Trimming, July–August	3.5	4.9	.9–28
Trimming, September–June	96.5	1.0	. . .
Month of calving			
Calving, March–October	54.8	76.7	4.1–>
Calving, November–February	45.2	1.0	. . .
Stage of lactation			
Trimming, ≥ 33 DIM[3]	70.7	5.6	2.9–11
Trimming, < 33 DIM	29.3	1.0	. . .
Sole ulcer and trim interval[4]			
Interval, 57–165 d or 176–197 d			
Sole ulcer, degrees 4–5	3.2	2.1	.4–11
Sole ulcer, degree 3	3.5	.4	.1–2.0
Sole ulcer, degrees 1–2	7.4	1.4	.4–4.8
No sole ulcer	37.5	1.2	.6–2.6
Interval, 167–175 d or above 197 d			
Sole ulcer, degrees 4–5	3.2	7.6	1.7–35
Sole ulcer, degree 3	3.5	2.9	.7–12
Sole ulcer, degrees 1–2	3.5	.1	0–.6
No sole ulcer	38.2	1.0	. . .

[1]In addition, herd-year of calving is included in the model.

[2]Confidence interval.

[3]DIM ≥ 33, mean ± SD = 76 ± 37 d; DIM < 33, mean ± SD = 20 ± 10 d.

[4]Interval in days between previous and current trimming.

analysis of risk factors for sole ulcer (4), a similar pattern was found and discussed. The not completely parallel LCP curves could indicate violation of model assumptions as a reason, but it is very likely that different treatment of the cows according to their status at second trimming in the preceding lactation have produced this effect, which, however, is also likely to occur if claw health data are used for monitoring purposes. Analyses of recordings at second trimming in a lactation, among others, are necessary to elucidate this question further. Because claw trimming during recording of claw health inevitably will influence the course of the recorded disorder, this potential bias must be controlled in surveys and monitoring programs.

Interdigital dermatitis and hyperplasia were not associated with erosion. Competition between recordings of the different digital disorders could be a possibility, i.e., if a severe case of one disorder were observed, less obvious signs of another disorder might have been overlooked. This finding, however, does not support the hypothesis that heel erosion and interdigital dermatitis have the same etiology. In fact, the OR were less than one. Also, claw health at previous trimming was not associated with erosion at current trimming. More intense culling of lactation 1 cows with digital disorders could have altered results of erosion in lactations 2 to 9. Lack of statistical power due to a too small sample size could also be an explanation for this unexpected result. The applied coding sys-

TABLE 3. Final logistic regression model of heel erosion in lactations 3 to 9. Heel erosion of the degree 1 and degrees 2 to 4 occurred among 31.3, and 41.7% of the 259 cows.

Description of variables[1]	Percentage of cows	Odds ratio	95% CI[2]
Parity			
Lactations 4–9	47.9	2.1	1.1–3.9
Lactation 3	52.1	1.0	. . .
Stage of lactation			
Trimming ≥ 33 DIM[3]	72.2	4.9	2.3–10
Trimming < 33 DIM	27.8	1.0	. . .
Disease treatments			
Digital disease	3.1	11.1	.8–150
No disease or other than digital	96.9	1.0	. . .
Sole ulcer and trim interval			
Interval, 57–165 d or 176–197 d			
Sole ulcer, degrees 4–5	5.4	5.6	1.3–24
Sole ulcer, degree 3	7.3	2.5	.7–9.6
Sole ulcer, degrees 1–2	3.0	1.5	.3–8.0
No sole ulcer	47.1	4.4	1.8–11
Interval, 167–175 d or above 197 d			
Sole ulcer, degrees 4–5	6.9	14.4	3.5–60
Sole ulcer, degree 3	3.9	8.2	1.7–41
Sole ulcer, degrees 1–2	.8	8.4	.4–172
No sole ulcer	25.6	1.0	. . .
Digital skin disorders at previous trimming			
Hyperplasia or dermatitis degrees 1–4	7.3	4.2	1.2–14
No skin disorders	92.7	1.0	. . .
Heel erosion at previous trimming			
Degrees 3–4	2.3	2.8	.2–39
Degree 2	13.5	6.7	2.1–21
Degree 1	20.8	1.9	.8–4.5
No heel erosion	63.4	1.0	. . .

[1]In addition, herd-year of calving is included in the model.

[2]Confidence interval.

[3]DIM ≥ 33, mean ± SD = 78 ± 38 d; DIM < 33, mean ± SD = 15 ± 10 d.

tem in this study, resulting in an estimation of repeatability on the cow foot level, should, however, be very sensitive with respect to detecting association if present.

The effect estimates for lactations 3 to 9 are shown in Table 3. The increasing risk and severity of erosion with increasing age is evident. No seasonal effects were revealed, indicating that older cows were less exposed or susceptible to season specific risk factors like temperature, hygiene, and management. Stage of lactation had an effect similar to that of lactation 2, and veterinary treatments for digital disorders were strongly associated with erosion, although the estimates were imprecise.

Ulcer and trim interval were associated with erosion in a way very similar to that of lactation 2, but the effect was stronger. This consistency further supports the prior arguments. Interdigital dermatitis and hyperplasia (pooled) at previous trimming had a very strong but imprecisely determined effect on erosion. This finding is consistent with erosion as a chronic condition initiated by an infection in the interdigital skin. Such a pathogenesis is, however, difficult to elucidate further through observational studies, but these findings indicate that a distinction is not important for practical purposes. Also, Toussaint Raven (23) claims that it is not essential to know the exact pathogenesis, because both an unspecific bacterial or chemical and a specific bacterial condition are enhanced by moist, warm, and unhygienic environment.

In contrast with the model of erosion in lactation 2, heel erosion at previous trimming was strongly associated with erosion recorded at current trimming in lactations 3 to 9. Further, the estimates give some indication of a dose response effect. This high repeatability provides good arguments for performing individual cow recordings of claw health on a routine basis. The repeatability from lactation 2 or higher combined with the lack of repeatability from lactation 1 to 2 indicates that the etiology of heel erosion in lactation 1 differs from the etiology in later lactations. Specific infection could play a bigger role in lactation 1.

Interdigital Dermatitis

The effect estimates for dermatitis in lactation 1 are shown in Table 4. Trimming in July to August was associated with an OR of 4.3, and calving in July to October was associated with an OR of 4.1. This seasonal pattern was very similar to the pattern of erosion in lacta-

TABLE 4. Final logistic regression model of interdigital dermatitis in lactation 1. Interdigital dermatitis of the degree 1 and degrees 2 to 4 occurred among 2.5, and 2.0% of the 1170 cows.

Description of variables[1]	Percentage of cows	Odds ratio	95% CI[2]
Month of trimming			
Trimming, July–August	13.6	4.3	1.3–14
Trimming, September–June	86.4	1.0	. . .
Month of calving			
Calving, July–October	45.8	4.1	1.6–11
Calving, November–June	54.2	1.0	. . .
Sole ulcer			
Degrees 4–5	6.9	2.0	.7–5.8
Degree 3	14.5	1.0	.4–2.5
Degrees 1–2	7.1	.8	.2–3.7
No sole ulcer	64.6	1.0	. . .
Heel erosion			
Heel erosion, degrees 3–4	1.2	4.0	.3–49
Heel erosion, degree 2	6.2	7.3	2.3–23
Heel erosion, degree 1	14.3	2.1	.9–5.0
No heel erosion	78.3	1.0	. . .

[1]In addition, herd-year of calving and interdigital hyperplasia are included in the model.

[2]Confidence interval.

tions 1 to 2, but there clearly were fewer months high in risk for dermatitis compared with erosion. Usually unhygienic, moist conditions are regarded as major determinants of dermatitis (5, 13, 25), although very dry conditions have also been observed to be predisposing (17). Because July to August usually includes the warmest months, bacterial growth could have been enhanced. The heifers calving in July to October are likely to have been on pasture in the late pregnancy period. Consequently, they are less well adapted to the claw environment in the cow barn: frequently, cows are brought into the cow herd from pasture immediately before calving. Exact information about the adaption period for the individual cows was, however, not available. Some herds also experience more cases of clinical digital disease (interdigital phlegmon and septic or aseptic pododermatitis) during late summer to fall (2), indicating that this period is critical to the integrity of the interdigital skin.

Severe cases of sole ulcer were weakly associated with dermatitis, but the cause and effect sequence is unclear. Severe interdigital infections (phlegmons) might have compromised horn production or constant exposure to moisture, manure, or physical trauma might have caused both types of disorder. Heel erosion was strongly associated with dermatitis. Due to the effect of interdigital lesion on erosion, this was expected, although it was not a necessity due to different coding systems for independent and dependent variables. The tendency to a dose response effect indicates, as previously discussed, a causal relationship. Although only 11 cases of interdigital hyperplasia were recorded, this factor was important in the model (estimates not shown). For practical purposes, it is probably more useful to regard hyperplasia combined with dermatitis as a severe case of either dermatitis or hyperplasia.

March to October included the high risk months of calving for dermatitis in lactations 2 to 9 (Table 5), and the explanations previously suggested may also be valid in this age group. The cows without sole ulcer in lactation 3 and 4 to 9 were at 2.3 to 2.9 times higher risk of dermatitis compared with lactation 2. Sole ulcer was a risk factor in lactation 2 and a protective factor in lactation 3. This mixed pattern could be spurious or caused by more intense culling of cows predisposed for both disorders. However, combined with the modest association in lactation 1, it can be concluded that sole ulcer is not an important risk factor for dermatitis.

TABLE 5. Final logistic regression model of interdigital dermatitis in lactations 2 to 9. Interdigital dermatitis of the degrees 1 to 4 occurred among 7.6% of the 542 cows.

Description of variables[1]	Percentage of cows	Odds ratio	95% CI[2]
Month of calving			
Calving, March–October	52.8	4.5	1.0–21
Calving, November–February	47.2	1.0	. . .
Parity and sole ulcer			
Parity 4 and no sole ulcer	16.1	2.3	.3–7.7
Parity 3 and sole ulcer degrees 1–5	7.0	1.0	.2–6.1
Parity 3 and no sole ulcer	17.9	2.9	1.0–8.7
Parity 2 and sole ulcer degrees 1–5	13.3	2.7	.8–8.9
Parity 2 and no sole ulcer	38.9	1.0	. . .
Disease treatment			
Digital limb, and severe[3]	13.8	.2	.0–1.4
Other[4]	25.6	.4	.1–1.1
No disease treatment	60.6	1.0	. . .

[1]In addition, herd-year of calving is included in the model. Parity 4 combined with occurrence of sole ulcer omitted due to imprecision.

[2]Confidence interval.

[3]Includes diseases digit, limb, or severe, either alone or in combination with others. See text for description.

[4]Treatments other than digit, limb, or severe.

TABLE 6. Final logistic regression model of interdigital hyperplasia in lactation 1. Interdigital hyperplasia occurred among 2.7% of the 405 cows.[1]

Description of variables	Percentage of cows	Odds ratio	95% CI[2]
Heel erosion			
Heel erosion, degrees 1–4	20.4	16.4	3.3–82
No heel erosion	79.6	1.0	. . .
Interdigital dermatitis			
Degrees 1–4	4.6	4.9	1.0–23
No interdigital dermatitis	95.6	1.0	. . .

[1]Only including data from six herds with occurrence of hyperplasia in lactation 1.

[2]Confidence interval.

Veterinary treatment (all treatments pooled) seemed to have a protective effect. Because approximately 75% of the treatments involved the use of antibiotics (12), a preventive or curative effect of these treatments could be possible. Of all cows treated, only 16.8% were assigned a diagnosis of digital disease.

Interdigital Hyperplasia

Only 11 cases (.9% of all lactation 1 cows) of interdigital hyperplasia occurred in lactation 1 and only in six herds. Cows from herds without cases in lactation 1 were excluded from the data set, and an analysis was performed without herd-year of calving in the model. A final model included only heel erosion and interdigital dermatitis (Table 6). The strong association between hyperplasia and these two conditions could be a result of swelling of the interdigital skin caused by erosion or interdigital dermatitis. This finding supports the statements made by Toussaint Raven (23), who regards interdigital hyperplasia as a symptom of chronic environmental infection and irritation that as such belongs to the interdigital dermatitis and heel erosion syndrome. Therefore, it seems reasonable to categorize hyperplasia in one of these categories. In a bivariate analysis, Nielsen and Smedegaard (9) similarly found that interdigital hyperplasia occurred more frequently with increasing severity of heel erosion.

TABLE 7. Final logistic regression model of interdigital hyperplasia in lactations 2 to 9. Interdigital hyperplasia occurred among 9.4% of the 343 cows.[1]

Description of variables	Percentage of cows	Odds ratio	95% CI[2]
Month of trimming			
Trimming, July–October	15.2	5.3	2.0–14
Trimming, November–June	84.8	1.0	. . .
Disease treatment			
All diseases except other[3]	14.0	2.8	1.0–8.2
No disease or other[4]	86.0	1.0	. . .
Interdigital hyperplasia previous trimming			
Present	4.4	169	32–889
Absent	95.6	1.0	. . .

[1]Only including data from 11 herds with occurrence of hyperplasia in lactation 2–9.

[2]Confidence interval.

[3]Includes diseases digit, limb, or severe, either alone or in combination with others.

[4]Treatments other than digit, limb, or severe.

In lactations 2 to 9, 32 cases (5.9%) occurred in 11 herds, including all six herds with cases in lactation 1. Data from herds without any cases were excluded, and the data were similar to lactation 1, analyzed without including herd-year of calving (Table 7). The markedly higher risk during summer to fall is in good agreement with Cirlain (3), who reported that clinical cases of hyperplasia occur more frequently in warmer periods of the year. The relatively strong association with disease treatment for all diseases (except other) cannot be explained satisfactorily. Hyperplasia could be a sequel to a case of digital disease responding poorly to treatment, but hyperplasia was not more strongly associated with digital than with diseases different from other.

The very pronounced repeatability from one lactation to another was expected, because this condition is regarded as difficult to treat with a high probability of recurrence (3, 5, 24, 25). A strong genetic component of this disorder has been found (3), and very poor conditions of tracks leading to pasture are known to increase the risk suddenly (17).

General Discussion

Initial analyses revealed that year of calving and herd had systematic effects. Consequently, herd-year of calving was forced into all models of erosion and dermatitis to account for some of the herd and season specific factors that are probably very important etiological factors. Such factors are, for example, skill of claw trimmers, genetic characteristics of the herd, quality of floors and stalls, type and amount of bedding, type of grazing areas (wet, dry, or stony), amount of micro minerals in the plants, growth and precalving preparation of heifers, veterinary practice, possible systematic changes in recording procedures, changes in the feed supply—especially the highly variable supply of fodder beets and fresh grass, weather conditions, and changes in farm workers. The effect estimates of the individual herd-years of calving were highly variable. Detailed descriptions of herd factors (stalls and hygiene) and prevalences of the different digital disorders in each herd are given elsewhere (11, 21, 22). For herd health management and research purposes, it is very important to reveal and to provide effect estimates of such herd specific conditions with effect on digital health. In the analysis of hyperplasia, the herd effect is controlled for much less efficiently.

Evaluating the estimates in Tables 1 to 7 together, a similarity of epidemiological patterns of heel erosion and interdigital dermatitis in lactation 1 is evident. Consequently, it is likely that the abrupt environmental change associated with first calving is an important causal component, perhaps in association with a specific pathogen. In consequence, it seems reasonable to pool these two disorders in lactation 1 if the data are to be used for monitoring purposes. For analytical purposes, such a simplification probably could increase the statistical power with respect to detecting predisposing factors in the herds. A pooling definitely is not justified in lactations 2 to 9, due to the marked differences in the effects of 1) parity (steady increase with age in risk of heel erosion but not in risk of interdigital dermatitis), 2) disease (a risk factor for heel erosion and hyperplasia but protective for dermatitis), 3) claw health at previous trimming (previous interdigital lesions associated with current heel erosions, but previous heel erosion not associated with current interdigital lesion), and 4) difference in repeatability (interdigital lesions were not repeatable [infectious disease—local immunity?], whereas heel erosion was repeatable [long lasting or not sufficiently severe to remove cows from the herds] among older cows).

Due to the more sporadic occurrence of interdigital hyperplasia in these herds, generalizations are more difficult. The low incidence and strong associations with heel erosion and interdigital dermatitis in lactation 1 justifies a pooling. It seems reasonable to pool with severe heel erosion in later lactations. In several cases, patterns differed among severe cases and less severe cases of claw disorders. The reason for this difference could be a higher risk of making classification errors when symptoms are less severe. Future monitoring programs might benefit from considering only severe cases.

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REFERENCES

1 Anderson, L., and K. Lundstrom. 1981. The influence of breed, age, body weight, and season on digital diseases and hoof size in dairy cows. Zentralbl. Veterinaermed. Reihe A 28:141.

2 Blom, J. Y. 1982. Forekomst af kliniske klovlidelser hos malkekoer i forskelligt staldmiljo. Page 128 *in* Rep. 532. V. Oestergaard and J. Hindhede, ed. Natl. Inst. Anim. Sci., Copenhagen, DK.

3 Cirlain, M. 1982. Hyperplasia interdigitalis in bulls. A genetic and epizootologic 6-year study. 4th Symp. Disorders Ruminant Digit. Paris, France.

4 Enevoldsen, C., Y. T. Gröhn, and I. Thysen. 1991. Sole ulcers in dairy cattle: associations with season, cow characteristics, disease, and production. J. Dairy Sci. 74:1284.

5 Greenough, P. R., F. J. MacCallum, and A. D. Weaver. 1981. Lameness in cattle. J. B. Lippincott Co., Philadelphia, PA; Toronto, Can.

6 Harrell, F. E. 1985. The practical value of logistic regression. Page 1031 *in* Proc. 10th Annu. SAS® User's Group Int. Conf. SAS Instit., Reno, NV.

7 Maton, A. 1987. The influence of the housing system on claw disorders in dairy cows. Page 151 *in* Cattle housing systems, lameness and behavior. H. K. Wierenga and D. J. Peterse, ed. Martinus Nijhoff for the Comm. Eur. Commun., Dordrecht, Neth.; Boston, MA.

8 Mortensen, K., and M. Hesselholt. 1982. Laminitis in Danish dairy cattle—an epidemiological approach. 4th Symp. Disorders Ruminant Digit., Paris, France.

9 Nielsen, E., and H. H. Smedegaard. 1984. Disease in legs and hooves with Black and white dairy cattle in Denmark. Rep. 568, Natl. Inst. Anim. Sci., Copenhagen, DK.

10 Oestergaard, V. 1985. Experimental housing systems for dairy cattle. Goals, materials, and design. Page 10 *in* Rep. 588. V. Oestergaard, ed. Natl. Inst. Anim. Sci., Copenhagen, DK.

11 Oestergaard, V. 1985. Environment in different housing systems for dairy cattle. Page 53 *in* Rep. 588. V. Oestergaard, ed. Natl. Inst. Anim. Sci., Copenhagen, DK.

12 Oestergaard, V., I. Thysen, and U. Henneberg. 1985. The effects of housing systems on margin above variable costs in the dairy herd. Page 210 *in* Rep. 588. V. Oestergaard, ed. Natl. Inst. Anim. Sci., Copenhagen, DK.

13 Peterse, D. J. 1986. Lameness in cattle. Page 1015 *in* Proc. 14th World Congr. Dis. Cattle, Dublin, Ireland.

14 Politiek, R. D., O. Distl, T. Fjeldaas, J. Heeres, B. T. McDaniel, E. Nielsen, D. J. Peterse, A. Reurink, and P. Strandberg. 1986. Importance of claw quality in cattle: review and recommendations to achieve genetic improvement. Rep. Eur. Assoc. Anim. Prod. Working group on claw quality in cattle. Livest. Prod. Sci. 15: 133.

15 Rowlands, G. J., A. M. Russell, and L. A. Williams. 1983. Effects of season, herd size, management system, and veterinary practice on the lameness incidence in dairy cattle. Vet. Rec. 113:441.

16 Rowlands, G. J., A. M. Russell, and L. A. Williams. 1985. Effects of stage of lactation, month, age, origin, and heart girth on lameness in dairy cattle. Vet. Rec. 117:576.

17 Smedegaard, H. H., I. Thysen, and E. Buchwald. 1982. Kronisk betaendelse og nydannelser i klovspalten hos malkekoer. Page 120 *in* Rep. 532. V. Oestergaard and J. Hindhede, ed. Natl. Inst. Anim. Sci., Copenhagen, DK.

18 Smit, H., B. Verbeek, D. J. Peterse, J. Jansen, B. T. McDaniel, and R. D. Politiek. 1986. The effect of herd characteristics on claw disorders and claw measurements in Friesians. Livest. Prod. Sci. 15:1.

19 Smit, H., B. Verbeek, D. J. Peterse, J. Jansen, B. T. McDaniel, and R. D. Politiek. 1986. Genetic aspects of claw disorders, claw measurements, and 'type' scores for feet in Friesian cattle. Livest. Prod. Sci. 15: 205.

20 Thysen, I. 1987. Foot and leg disorders in dairy cattle in different housing systems. Page 166 *in* Cattle housing systems, lameness and behavior. H. K. Wierenga and D. J. Peterse, ed. Martinus Nijhoff for the Comm. Eur. Comm., Dordrecht, Neth.; Boston, MA.

21 Thysen, I., E. Buchwald, J. Y. Blom, and H. H. Smedegaard. 1981. Skader og sygdomme i malkekoens klove. Page 49 *in* Rep. 515. V. Oestergaard and J. Hindhede, ed. Natl. Anim. Sci., Copenhagen, DK.

22 Thysen, I., E. Buchwald, J. Y. Blom, and H. H. Smedegaard. 1982. Staldtypens og staldindretningens betydning for klovsundheden hos malkekoer. Page 141 *in* Rep. 532. V. Oestergaard and J. Hindhede, ed. Natl. Inst. Anim. Sci., Copenhagen, DK.

23 Toussaint Raven, E. 1982. Some reflections after three symposia on bovine digital disorders. 4th Symp. Disorders Ruminant Digit., Paris, France.

24 Toussaint Raven, E. 1985. Cattle foot care and claw trimming. Farming Press, Ipswich, Suffolk, Engl.

25 Weaver, A. D. 1988. Cattle foot problems part 2: diseases of the horn and corium. Agri-Practice 9(2):35.

26 Williams, L. A., G. J. Rowlands, and A. M. Russell. 1986. Effect of wet weather on lameness in dairy cattle. Vet. Rec. 118:259.