Relationships between bovine hoof disorders, body condition traits, and test-day yields

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ABSTRACT

A designed field study was conducted on 1,962 first-lactation Holstein cows kept on 7 large-scale dairy farms in Germany, in loose-housing systems on standard slatted flooring. Records of hoof disorders at trimming composed of subclinical as well as clinical cases were combined with body measurements and body condition scores, test-day records, and further individual cow data. The 6 most frequent disorders were laminitis, also known as sole hemorrhage (57.3% of all cows), dermatitis digitalis (17.0%), dermatitis interdigitalis (7.9%), white line disease (12.6%), sole ulcer (7.1%), and interdigital hyperplasia (5.5%). The most important environmental effects were herd-visit date and stage of lactation. Heifers between 50 and 99 d in milk had the highest frequencies for laminitis. Lighter cows were less susceptible to laminitis and white line disease, but had a higher prevalence of interdigital hyperplasia. Relationships between stature and white line disease as well as relationships between body condition score and dermatitis digitalis were nonlinear, resulting in an improved disorder status of cows with an intermediate condition score and average stature. Increased biomechanical stress caused by different factors (weight, social rank, standing time) is a presumed effect that leads to an increased susceptibility for hoof diseases. From a management perspective, under- and overconditioning should be avoided. Milk production traits differed between cows with and without laminitis-related claw horn lesions. Fat percentage and fat-to-protein ratio in the first month before trimming were significantly decreased for cows with a positive laminitis status. Hence, this finding points to metabolic disorders being associated with a higher risk for hoof diseases. Estimates of heritabilities for laminitis, dermatitis digitalis, dermatitis interdigitalis, white line disease, and sole ulcer were 0.09, 0.14, 0.10, 0.11, and 0.06 when applying a threshold model with a probit link function.

Key words: hoof disorder, laminitis, body condition status, test-day production

INTRODUCTION

Feet and leg diseases are a persistent, nondecreasing problem in modern intensive dairy production. Disorders of the bovine hoof, sometimes also called claw disorders, are major reasons for a reduced lifespan (Cramer et al., 2009), impaired well-being, and inferior productivity (Sogstad et al., 2006). Early detection of the respective disease is of immense importance for reasons of animal welfare and the economics of the dairy operation. When a cow is observed with lameness, clinical status has already been reached. However, at the time of hoof trimming, subclinical cases can often be recognized and early action can be taken. At the same time, routine hoof trimming allows for targeted data collection. In recent years, several studies have demonstrated the informational value and reliability of such data for scientific investigations and genetic selection (e.g., Koenig et al., 2005; van der Waaij et al., 2005; Swalve et al., 2008; van der Linde et al., 2010). With the introduction of the claw health index in the Netherlands (Stoop et al., 2010; van der Linde et al., 2010), a routine genetic evaluation was implemented.

The relationships between hoof health and dairy production (e.g., Koenig et al., 2005; van Straten et al., 2011), conformation traits (e.g., van der Waaij et al., 2005), and fertility (e.g., Sogstad et al., 2006; Buch et al., 2011) are topics of recent studies, and they illustrate the complexity of the physiological background. The energy balance status of the cow plays a key role in hoof health, especially during the transition period, which can be a difficult time for the cow, with the occurrence of metabolic diseases, such as milk fever, ketosis, and retained placenta, or diseases that often may not appear clinically, such as laminitis (LAM; Goff and Horst, 1997). Test-day milk data can be useful for monitoring the nutrient balance (Toni et al., 2011). Toni et al. (2011) emphasized the relevance of the fat-to-protein ratio in early lactation as a helpful indicator of lipomobilization and metabolic challenge.

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Several studies have reported the nonlinearity of associations between fat-to-protein ratio and the occurrence of involuntary culling (Bergk and Swalve, 2011; Toni et al., 2011) as well as incidences of diseases such as retained placenta, metritis, or displaced abomasum (Toni et al., 2011). van Straten et al. (2011) combined test-day data with claw diagnosis and found reduced milk fat percentages for cows with claw horn lesions. An obvious connection between reduced milk fat percentage and LAM is SARA, which is an initial point for a cascade of events causing subclinical LAM as well as closely associated diseases (Greenough et al., 2007). At the same time, SARA can induce milk fat depression (Plaizier et al., 2008). A factor closely associated with lipid metabolism is BCS. The intercalving profile of BCS is similar to an inverted lactation curve for milk yield (Roche et al., 2006, 2007). In general, it is assumed that overconditioning causes an increased risk of periparturient metabolic disorders (Roche et al., 2009), such as milk fever (Roche and Berry, 2006) and ketosis (Gillund et al., 2001). At the same time, reduced production and reproductive performance are known problems for underconditioned cows (Roche et al., 2009). Very few studies have examined the relationship between BCS and lameness. The studies by Gearhart et al. (1990) and Hoedemaker et al. (2009) both found significant relationships, although in opposite directions. To the best of our knowledge, a differentiated analysis of individual claw disorders associated with the cows' body condition status has not been described.

The goal of the present study was to investigate the relationships of individual hoof disorders with BW and BCS as well as test-day dairy production parameters. Specifically, the aims of the study were to examine the effect of known environmental effects, to investigate new effects, especially body and metabolic condition, and to estimate heritabilities for the main claw disorders. The present study focuses on LAM, also called sole hemorrhage, which is considered a major predisposing source for lameness caused by claw disorders (Vermunt and Greenough, 1994) and which proved to be the predominant disorder in the present study. It is known from various studies that claw diseases are strongly influenced by housing (Sogstad et al., 2005; Barker et al., 2009), flooring (Somers et al., 2003, 2005; Telezhenko et al., 2008), parity (Sogstad et al., 2005; Barker et al., 2009; Swalve et al., 2011), and stage of lactation (Pijl and Swalve, 2006). The design of the experiment therefore considered these findings and also included the planning of sizeable contemporary groups. Data were collected in 7 large herds with very similar housing and management (i.e., standard slatted flooring and little use of straw for bedding). The study

focused on first-parity cows with a hoof-trimming time period between the 50th and 150th DIM.

MATERIALS AND METHODS

Study Design and Data

A fixed team of 3 persons, a veterinarian, a professional hoof trimmer, and a field technician, recorded all measurements of each cow at hoof trimming for 1,962 first-lactation Holstein cows during the period of March 2008 to December 2009. The team assessed disorder status, subsuming subclinical and clinical claw disorder cases. Cows were from 7 high-producing commercial dairy herds in northeastern Germany that had large herd sizes of approximately 500 to 2,500 cows. Farms had been selected according to similar housing and management conditions and to reflect the most common system for large-scale dairy herds with indoor housing all year round; all had loose-housing systems and standard slatted flooring, and cows were fed a TMR. The main focus was on cows from 50 to 150 DIM. During this period, the cow is at peak lactation; accordingly, exposure to general stress and metabolic stress is highest and susceptibility to risk factors is increased. However, because of restrictions in farm management and time budgets of the team, not all first-lactation cows in each herd could be included. In addition, focusing on a very specific stage of lactation was only partly achieved because of too many logistical constraints. In summary, 62% of all observations fell into the first third of lactation, and only 10% of observations were made after 200 DIM. As observed by Pijl and Swalve (2006), LAM incidence is highest between 50 to 100 DIM. Hence, by focusing on the first third of the lactation, we expected to observe increased rates of LAM cases compared with studies randomly trimming cows throughout all stages of the lactation.

Because herd and visit date within herd were expected to be the most prominent environmental effects, data collection focused on acquiring sizeable herd-visit-date cohorts. Approximately 30 to 60 trimmings including all measurements were feasible per day, depending on specific conditions on the farms. Actual cohort sizes for a total of 24 herd-visit-date cohorts varied from 31 to 165, with larger numbers being the result of consecutive working days. This general setup made it possible to form contemporary groups of primiparous cows, all having calved in the same season and being in a similar stage of lactation.

Data recorded at the time of trimming (i.e., claw diagnoses and supplemental measurements) were recorded electronically on the spot by using a personal

digital assistant. The personal digital assistant was equipped and programmed for this purpose and was preloaded with information on all cows in the herd. For all cows, only the first trimming while lactating was included in the present study. As a standard practice on all the farms included, the first trimming in the life of the animal had occurred as a heifer, usually at an age of 15 to 20 mo.

Claw diagnoses were recorded for the hind legs only. The individual cow was scored as affected (score of 1) if one or both hoofs showed disorders, or as 0 otherwise. A recording of more than one disorder was possible. A score of 1 included subclinical and clinical cases. The 6 most important disorders were subjected to analysis. Disorders, grouped into noninfectious and infectious diseases, were LAM (also known as sole hemorrhage), white line disease (**WLD**), sole ulcer (**SU**), and interdigital hyperplasia (**IH**), representing the noninfectious diseases. Infectious disorders were dermatitis digitalis (**DD**; also known as foot warts or Mortellaro's disease) and dermatitis interdigitalis (**DID**; also known as foot rot). Prevalence rates are shown in Table 1. Because clinical as well as subclinical cases were included, the term "disorder" is preferred instead of "diseases." The most frequent diagnosis by far was LAM (57.3%). This comparatively high value may be explained by the fact that subclinical and clinical cases were included and by the focus on the critical time period within lactation.

Age of the cows at phenotyping varied from 21 to 41 mo (28.3 ± 3.2 mo). For parts of the evaluation, the hoof disorders LAM, WLD, and SU were aggregated into the group laminitis-related claw horn disorders (**LRCHD**). This grouping effectively meant that the individual cow showed at least 1 of the 3 named disorders and none of the others (DD, DID, IH). By grouping LRCHD, the intention was to enable an analysis comparing cows with a score of 1 ($n = 933$) with completely healthy animals ($n = 581$). Cows with an infectious claw disorder or IH were not included in this part of the analysis.

Additional measurements taken at the time of trimming were BW, BCS, backfat thickness (**BFT**), and

height at the sacrum (**HS**). Body weight was measured by scales integrated into the cattle crush used for trimming, and HS was measured using a measuring tape. Mean values for BW and HS were 530.2 kg (± 55.7) and 145.3 cm (± 3.8), respectively. Body condition was scored using a 5-point scale with 0.25-unit increments. The BCS values were characterized by a mean of 2.68 (± 0.56). Following the method of Staufenbiel (1997), the measurement for BFT was taken at the point of maximum fat, which is approximately between one-quarter and one-fifth of the way between the tuber coxae and tuber ischiadicum. A portable ultrasound generator (Aloka 210, Hitachi Aloka, Tokyo, Japan) with a linear scanner and a frequency of 5 MHz was used. Cows had a mean BFT of 25.6 mm (± 9.9). Each farm was visited up to 5 times, but each cow was recorded only once.

Data collected on the farms were combined with pedigree data, test-day data, and further individual cow data (e.g., date of birth, date of calving, conformation scores, date of and reason for culling) from Vereinigte Informationssysteme Tierhaltung w. V. (Verden an der Aller, Germany), the central computing center for milk-recording data for the Holstein breed in Germany. Conformation scores were taken from the official classification and were from dates fully independent of the trimming dates. Most of the cows in the present study (i.e., a total of $n = 1,685$ cows of all $n = 1,962$ cows) had conformation scores as classified by the local herd-book association. With respect to feet and leg traits, results from the overall index for feet and legs and the individual traits rear legs side view, hock quality, rear legs rear view, locomotion, and foot angle were available. In the official classification system, raters also attempt to score cows in the first half of the lactation. This resulted in 80.5% of classification scores within 100 d of the trimming date, with 24% of the records deviating by only ± 25 d from the trimming date and 35% between 75 and 25 d before the trimming date.

The 7 participating large-scale dairy farms were also part of a progeny-test program; this ensured that sires

Table 1. Prevalence rates for the 6 most important disorders and herd-visit prevalence interval

Name of disorder	Abbreviation	All observations (%)	Within-herd date of visit	
			Minimum (%)	Maximum (%)
Noninfectious				
Laminitis	LAM	57.3	25	92
White line disease	WLD	12.6	2	32
Sole ulcer	SU	7.1	0	25
Interdigital hyperplasia	IH	5.5	0	20
Infectious				
Dermatitis digitalis	DD	17.0	0	44
Dermatitis interdigitalis	DID	6.9	0	37

had been well distributed across herds and had had several daughters per herd. In total, all $n = 1,962$ cows were descendants of 274 sires, with an average number of daughters of 7.1; 48 bulls had more than 10 daughters.

Farm visits for trimming of cows were scheduled such that a sizeable group of cows fitted the desired age requirements; hence, we did not attempt to include all possible cows from each herd. Therefore, cows in the study are to be regarded as a sample from each herd. Dairy production data for all cows included in the study were compared with those of their contemporaries from calving years 2007 to 2009. First-lactation dairy production, uncorrected for age, for cows having at least a lactation length of 270 d and limiting the lactation length to 305 d, was 8,683 kg of milk, 338 kg of fat, and 291 kg of protein for 5,446 contemporaries versus 8,731 kg of milk, 337 kg of fat, and 289 kg of protein for 1,825 study cows fulfilling the same lactation length requirement.

Statistical Analyses

Because of the binary nature of the disorder data, for the analysis of fixed environmental effects as well as for the estimation of genetic parameters, a threshold model was used. The models were developed for each disorder separately by subsequently eliminating the nonsignificant ($P > 0.05$) effects. In total, the effects of herd-visit date, lactation stage (grouped in classes, as a continuous covariate), age at trimming, age at calving, BW, stature, BCS, and BFT were evaluated in various models. Interactions between BW and age at calving as well as between BCS and age at calving were also checked. After these checks, the models chosen according to best fit or simplicity when compared with more complicated models of equal fit were

$$PR_{LAM}(Y_{ijkn} = 1) = \theta (\mu + HVD_i + DIM_j + BW_k + animal_n),$$

$$PR_{DD}(Y_{iln} = 1) = \theta (\mu + HVD_i + BCS_l + animal_n),$$

$$PR_{DID}(Y_{in} = 1) = \theta (\mu + HVD_i + animal_n),$$

$$PR_{WLD}(Y_{ikmn} = 1) = \theta (\mu + HVD_i + BW_k + HS_m + animal_n),$$

$$PR_{SU}(Y_{iln} = 1) = \theta (\mu + HVD_i + BCS_l + animal_n), \text{ and}$$

$$PR_{IH}(Y_{ikn} = 1) = \theta (\mu + HVD_i + BW_k + animal_n),$$

where PR is the probability of occurrence of the disorder, Y_{ijklmn} is the disorder score (1 = positive finding), θ is the probit link function, μ is the overall mean, HVD_i is the fixed effect of herd-visit date ($i = 1, \dots, 24$), DIM_j is the fixed effect of stage of lactation as grouped into classes ($j = 1, \dots, 5$ for DIM: <50, 50–99, 100–149, 150–149, ≥ 150), BW_k is the fixed effect of BW ($k = 1, \dots, 3$ for BW grouped into classes as <500 kg, 500–549 kg, ≥ 550 kg), BCS_l is the fixed effect of BCS ($l = 1, \dots, 3$ for scores grouped into classes as <2.5, 2.5–3.0, > 3.0), HS_m is the fixed effect of HS ($m = 1, \dots, 3$ for measurements in centimeters grouped into classes as <143, 143–147, > 147), and $animal_n$ is the random effect of animal.

Conformation scores were grouped into classes. For the overall index, on a 100-point scale, most values usually fall within the range of 70 to 85 points. Hence, 4 class groups were formed, with 1 being <75, 2 being 75–77, 3 being 78–80, and 4 being > 80 points. For the individual linear traits, scored on a 1 to 9 scale, groups were formed such that meaningful frequencies fell within the class limits. This resulted in the classes 1 = scores 1 and 2, 2 = scores 3 and 4, 3 = score 5, 4 = scores 6 and 7, and 5 = scores 8 and 9. As an initial scan, possible associations between conformation and LAM were evaluated using a chi-square test for the distribution of disorder status for LAM across conformation score classes. Subsequently, an SAS GLIMMIX analysis (SAS Institute Inc., Cary, NC) including a fixed effect-only model was used. Hereby, a model similar to the model for LAM, as given above, was used but with the random effect of the animal was dropped and the conformation score classes were included for 1 trait at a time.

The relationship between test-day dairy production and claw horn lesions was investigated, as suggested by van Straten et al. (2011). Monthly test-day fat percentage, protein percentage, and fat-to-protein ratio were considered continuous traits, and disorder status was included as a fixed effect. The significance of the effects was determined by using a full model, including herd-visit date, stage of lactation (grouped in classes, as a continuous covariate), test-day milk production (for contents traits only), and disorder status. After eliminating effects that were not significant, the final linear mixed model was

$$Y_{ijk} = \mu + HVD_j + b_1(DIM) + LRCHD_k + b_2(MILK) + e_{ijk},$$

where Y_{ijk} is the phenotypic value of trait i , μ is the overall mean, HVD_j is the fixed effect of herd-visit date ($j = 1, \dots, 21$), $LRCHD_k$ is the fixed effect of sta-

tus of laminitis-related claw horn disorders ($k = 1-2$), $b_1(\text{DIM})$ is the regression coefficient for stage of lactation, $b_2(\text{MILK})$ is the regression coefficient for test-day milk production (kg), and e is the random residual effect. The term $b_2(\text{MILK})$ was included only for the analysis of test-day fat percentage and test-day protein percentage. The above model was applied for all cows that had test-day information for 1, 2, 3, 4, and 5 mo before the time of hoof trimming and that did not have a positive score for LRCHD and an infectious disorder at the same time. This resulted in forming 5 subsets comprising 1,407, 995, 741, 446, and 284 cows for which the respective test-day information was available. Because cows included in 1 subset differed for stage of lactation, a second, analogous analysis was conducted, restricting the data only to cows that had a hoof-trimming date within the first 100 DIM and considering only 1, 2, or 3 test days before trimming.

Data preparation, editing, and examination of alternative modeling of fixed effects were conducted using the statistical package SAS 9.1 (SAS Institute Inc.). For the estimation of genetic parameters using animal models, the ASREML software version 3.0 (Gilmour et al., 2009) was applied. For all threshold models, a probit-link function was used.

RESULTS AND DISCUSSION

Aggregation across the 6 disorders resulted in 70% of the inspected cows having at least 1 claw disorder. This finding resembles the report by van der Linde et al. (2010), who found a similar value on the order of 69% for Dutch Holstein cows. In other studies from the Netherlands, Somers et al. (2003) and van der Waaij et al. (2005) reported even more than 70%. The predominant disorder in the present study was LAM, in agreement with other studies (e.g., Swalve et al., 2005, 2008; van der Waaij et al., 2005; van der Linde et al., 2010). In the study by Buch et al. (2011) on almost 64,000 cows, the prevalence was much lower than in this study. This is largely because “mild” or subclinical cases of diseases were included. For LAM, the focus on a lactation stage of between d 50 and 150 after calving also increased prevalence, as was expected from a previous study (Pijl and Swalve, 2006).

If more than 1 disorder was detected, the most frequent combination was LAM $\times$ DD ($n = 231$), followed by LAM $\times$ WLD ($n = 181$). As shown in Table 1, the differences in prevalence rates between herds and herd visits are remarkable even though housing and management conditions had been highly standardized. This result is in agreement with that by Koenig et al. (2005), who found considerable differences for claw disorders between herds with similar management conditions.

Hence, no obvious causes for these differences have been identified. Rather, we hypothesized that complex relationships between the physiological backgrounds and a contribution of a genetic predisposition may be causes for this variation.

Fixed Effects

As expected, herd-visit date significantly affected all disorders ($P < 0.001$). Stage of lactation showed a statistically significant ($P < 0.001$) influence only on LAM. The least squares means displayed in Table 2 demonstrate a significantly increased susceptibility between the 50th and 100th DIM. This finding points to effects resulting from the high metabolic load observed at the time of peak milk yield. Tarlton et al. (2002) demonstrated that events around calving and the onset of lactation lead to histological changes in the claws of heifers. A thickening and distortion of the laminae and corium induce changes in the biochemistry of the connective tissue, which cause a loss of structural integrity of the suspensor apparatus. As a result, increased metabolic stress eventually affects the sole and the white line and thus could be one main factor in the etiology of LAM. The effects arise with a delay of several weeks and can be identified during the claw trimming, which consequently leads to an increased frequency of LAM at the end of the first third of the lactation, when the metabolic system of the heifer additionally is challenged by the peak of lactation. When analyzing cows of different parities, Sogstad et al. (2005) found most hemorrhages for cows that had calved 3 to 6 mo earlier. Heifers appear to be more vulnerable to hemorrhages and presumably show earlier symptoms. Manske et al. (2002) detected a greater risk of hemorrhages in primiparous cows in midlactation; however, these authors did not include mild hemorrhages, which possibly would have been identified at an earlier stage.

The metabolic load of the high-yielding dairy cow in early lactation is a key factor affecting the susceptibility to diseases. It is well known that a positive energy balance in early lactation can hardly be achieved by

Table 2. Least squares means $\pm$ SEM for the prevalence of laminitis stratified by stage of lactation¹

DIM	Laminitis (%)
<50	46.74 $\pm$ 2.65 ^c
50–99	70.09 $\pm$ 1.99 ^a
100–149	59.25 $\pm$ 3.16 ^b
150–199	48.36 $\pm$ 3.68 ^{bc}
>200	53.99 $\pm$ 4.55 ^{bc}

^{a-c}Least squares means within a column with different superscripts differ ($P < 0.05$).

¹Determined using the probit link function.

feeding. The additional mobilization of endogenous energy reserves results in decreasing BW and BCS (Mao et al., 2004; Berry et al., 2006; Roche et al., 2006). For decreases in BW and BCS, an association with metabolic health and fertility has been demonstrated (Roche and Berry, 2006; Berry et al., 2007). Thus, possible subsequent effects on claw health may be assumed.

For WLD, BW and height had a significant effect on the susceptibility to the disorder. As can be seen from Table 3, cows with low BW and intermediate heights show the lowest prevalence rates. When classes of both effects were combined into a single fixed effect, the general findings, as seen in Table 3, were unchanged, but further comparisons could be made (Figure 1). Small animals showed a high susceptibility to WLD across all BW classes. The highest susceptibility was found for short, overweight cows, whereas tall and heavy cows ranked second in prevalence rates.

For LAM, only the effect of BW was significant (Table 4). Again, heavier cows were found to have higher prevalence rates. We assumed that cows with increased BW would experience more compressive stress on the claw, resulting in collagen fibers of the suspensory apparatus to be stretched. In addition, Tarlton et al. (2002) proved the connective tissue of the hoof was weakened by events associated with calving and the start of lactation. These authors also assumed this to be a primary factor in the development of claw horn lesions. Hinterhofer et al. (2006) showed that mechanical stress is increased on slatted floors. On the contrary, heavier BW may also be a sign of overfeeding, with consequences for the metabolic condition. Gearhart et al. (1990) reported that cows that are overconditioned

Table 3. Least squares means $\pm$ SEM for the prevalence of white line disease stratified by height at the sacrum and BW¹

Item	White line disease (%)
Height at sacrum (cm)	
<143	11.91 $\pm$ 1.69 ^a
143–147	7.25 $\pm$ 0.94 ^b
>147	10.87 $\pm$ 1.47 ^a
BW (kg)	
<500	7.23 $\pm$ 1.27 ^b
500–549	10.52 $\pm$ 1.28 ^{ab}
$\geq$ 550	12.31 $\pm$ 1.56 ^a

^{a,b}Least squares means within a column with different superscripts differ ($P < 0.05$).

¹Determined using the probit link function.

at drying off are 7 times more prone to claw problems after calving than are cows in good condition. A high level of concentrates, especially a ration rich in carbohydrates, can be an initiating factor for LAM (Vermunt and Greenough, 1994). Hence, both factors, the weight pressure of a heavy-weight cow and the metabolic condition resulting from overfeeding, can be assumed to affect LAM as well as WLD. White line disease is attributed to the group of LAM-associated claw diseases, and both are often classified as “feed-related” (e.g., Buch et al., 2011). The dermatitis-like diseases are considered “hygiene-related” and infectious. In the present study, the dermatitis-like diseases were independent of size and BW. However, a highly significant effect of BCS on the prevalence of DD as well as on SU was found (Table 5). Animals that deviated downward from the expected BCS (2.5 to 3.0 BCS nadir at the time of peak yield) were more susceptible. Overconditioned cows also showed a trend with an increased prevalence rate for DD. Roche et al. (2009) described nonlinear associations between BCS and several production and health traits: cows with a lower BCS at calving (<3.0) show reduced production and reproduction, whereas a higher BCS at calving (≥ 3.5) is associated with reduced DMI, lower milk production, and an increased risk of metabolic disorders. With an increased BCS at calving, the BCS loss in early lactation is also increased, as reported by Roche et al. (2007). Thus, fatter cows at calving have a greater loss of BCS after calving but a higher BCS nadir. Data in the present study point to fatter cows exhibiting an infectious hoof disorder, DD, at an increased rate. Presumably, this could be due to increased stress caused by lipid metabolism (i.e. increased lipolysis) in addition to the metabolic load from milk synthesis. In total, the metabolic situation as summarized above leads to an organism that is highly stressed and cannot ensure a full immune defense. Weaknesses of the immune system in turn would result in an increased susceptibility to infectious diseases.

Figure 1. Prevalence rates for white line disease in combined classes of BW (1: <500 kg; 2: 500–549 kg; 3: ≥ 550 kg) and size (1: <143 cm; 2: 143–147 cm; 3: >147 cm).

To some extent, BCS is a reflection of the energy status of the cow. The relationship between energy balance and health was described by Collard et al. (2000), who hypothesized that thin cows and cows in severe negative energy balance were more predisposed to infectious diseases. This hypothesis appears to be in line with our results: thinner cows showed an increased prevalence of infectious disorders.

For SU, the effects of height and BW were not significant, whereas a significant effect was found for BCS, with a very clear trend (Table 5): cows with low BCS showed increased SU prevalence rates. A possible explanation for this finding may lie in the pathogenesis of SU. Sole ulcer is caused by mechanical pressure that crushes and destroys the horn-producing tissues between the flexor process of the pedal bone and the sole. As a consequence, the horn production in this specific region ceases and a hole in the sole develops, through which granulation tissue can emerge (Greenough et al., 2007). Long standing times and hard flooring enhance the negative biomechanical stress and can cause the pathogenesis. Schein and Fohrmann (1955) described the existence of significant relationships between rank and BW. In the present study, social rank was not measured by observations. We assumed that cows with low BCS were weaker animals, which would lead to a lower social rank. Low-ranking dairy cows spend less time lying (Galindo and Broom, 2000). Consequently, low-ranking cows have longer times standing or moving combined with longer routes when they are forced give way for high-ranking cows. This results in an increase in biomechanical stress on the claw and would lead to additional pressure and irritation of the dermal tissues in the SU-specific region. Cook et al. (2004) mentioned lying and standing times as influencing factors for overload of the connection between the third phalanx and horn capsule. Leonard et al. (1996) stated that reduced lying time exacerbates the development of claw lesions. Social rank and lying time hence may be seen as relevant factors contributing to SU. However, other factors, such as preceding hemorrhages, metabolic fac-

Table 5. Least squares means $\pm$ SEM for the prevalence of dermatitis digitalis and sole ulcer stratified by BCS¹

BCS	Dermatitis digitalis (%)	Sole ulcer (%)
<2.5	20.42 $\pm$ 1.91 ^a	10.20 $\pm$ 1.51 ^a
2.5–3.0	11.75 $\pm$ 1.23 ^b	6.42 $\pm$ 0.95 ^a
>3.0	15.04 $\pm$ 2.11 ^{ab}	3.04 $\pm$ 0.89 ^b

^{a,b}Least squares means within a column with different superscripts differ ($P < 0.05$).

¹Determined using the probit link function.

tors, and hormonal factors, also will play a role in the pathogenesis of SU.

For IH, BW was found to be highly significant (Table 4). In this case, the trend was opposite those for LAM and WLD. Lighter cows showed a higher probability of occurrence for IH.

Conformation

Abnormal hind leg conformation (i.e., an extreme status as defined by linear classification systems) is often associated with lameness and claw diseases. The quantification of these relationships in various studies shows genetic correlations that range from a small to a moderate magnitude and with varying direction, positive as well as negative. For Dutch Holsteins, van der Linde et al. (2010) estimated genetic correlations between -0.58 (DD—locomotion; scored as short stride to long stride) and 0.41 (SU—rear leg rear side view; scored as straight to sickled), but no statistically significant correlations for LAM. Van der Waaij et al. (2005) consistently identified positive correlations between LAM and conformation traits in the range of 0.11 (foot angle) and 0.26 (feet and legs).

In the present study, an initial examination of the relationship between disorder status and conformation traits consisted of a chi-square test for the distribution of classes of conformation scores across classes of disorder status. A highly significant influence ($P < 0.001$) of the German feet-and-legs index (i.e., an index of rear legs side view, foot angle, hock quality, rear legs rear view, and locomotion) on the probability of occurrence for LAM was observed. Among the individual traits, all traits except foot angle showed a significant association. Although for the feet-and-legs index and for the individual traits hock quality, rear legs rear view, and locomotion, the distribution for the affected animals always is shifted toward the left side (i.e., toward the unfavorable classes), the distribution of affected animals for rear legs side view was right-skewed because high scores in this case denote unwanted, more sickled legs. However, in an analysis with logistic models and

Table 4. Least squares means $\pm$ SEM for the prevalence of laminitis and interdigital hyperplasia stratified by weight¹

BW (kg)	Laminitis (%)	Interdigital hyperplasia (%)
<500	50.87 $\pm$ 2.70 ^b	9.28 $\pm$ 1.66 ^a
500–549	56.43 $\pm$ 2.16 ^{ab}	3.92 $\pm$ 0.85 ^b
≥ 550	60.25 $\pm$ 2.22 ^a	3.70 $\pm$ 0.84 ^b

^{a,b}Least squares means within a column with different superscripts differ ($P < 0.05$).

¹Determined using the probit link function.

accounting for fixed effects, a significant association could be confirmed for only the feet-and-legs-index and rear legs side view. Results were unaffected by a further inclusion of the difference between date of trimming and date of classification in the model. An increased susceptibility for LAM was found for more sickled legs. Chapinal et al. (2009) described changes in gait attributes (e.g., back arch, joint flexion, asymmetric steps) for cows with SU, but they found no significant differences for cows with hemorrhages. It can be assumed that different claw disorders cause pain in different ways, which leads to typical relieving postures and can be detected with individual auxiliary traits.

Test-Day Parameters

Subacute ruminal acidosis is known to be a common cause of LAM (Cook et al., 2004). It is a nonphysiological decrease of rumen pH and can be associated with reduced fat percentage in milk (Nordlund et al., 2004; Greenough et al., 2007). Fat-to-protein ratio is an often-used indicator of ruminal acidosis (Greenough et al., 2007). In the present study, no differences were found between fat and protein percentage as well as fat-to-protein ratio for cows with LRCHD, cows with infectious claw diseases, or cows without one of these disorders (data not shown). Figure 2 shows a retrospective inspection of test-day milk parameters. Monthly test-day parameters were compared for cows without a lesion and with at least 1 LAM-related disease for 1 to 5 mo before diagnosing at the time of trimming. Milk yield did not show a significant effect. For positive cows, lower fat percentages ($P = 0.015$), higher protein percentages ($P = 0.010$), and a lower fat-to-protein ratio ($P = 0.001$) were found to occur 1 mo (fat %), 3 mo (protein %), and 1 mo (fat-to-protein ratio) before claw trimming. In mo 2 to 4 before diagnosis, values for protein and fat percentages were very similar for affected and unaffected cows, which resulted in almost identical fat-to-protein ratios during this time for cows with and without LRCHD. When comparing cows at mo 1 before a positive diagnosis with healthy cows, a lower fat percentage accompanied by an almost equal protein percentage was observed; this was consequently reflected in a significantly lower fat-to-protein ratio. Assuming cases of SARA for the LRCHD-positive heifers, an explanation would be that because of the time needed for the horn tissue to grow, the symptom appeared with a delay. van Straten et al. (2011) found significant differences in test-day fat percentages at 2 and 5 mo before hoof trimming. For mo 2 before hoof trimming, van Straten et al. (2011) hypothesized that the delay could be explained by the rate of horn growing; for

the observed differences at mo 5, their explanation was that the cows would have experienced possibly repeated events of SARA. In the present study, although trends in this study for mo 5 were analogous to the findings of van Straten et al. (2011), significant differences were not observed, which could be attributed to the specifications of the study population focusing on trimming cows in the first trimester of lactation. Furthermore, the present study consisted of only first-lactation cows. Consequently, most heifers do not have the metabolic experience of SARA, either from a previous lactation or from an earlier stage in the current lactation.

Cows with LRCHD exhibited increased, but not significantly different, values for fat percentage at mo 2 and 3. This is in agreement with the report by de Vries and Veerkamp (2000) in their study of primiparous cows in early lactation that experienced a strong negative energy balance. No obvious explanation can be found for the significant difference in protein percentage between LRCHD-positive and LRCHD-negative cows when compared at mo 3 before trimming. Because of the nature of this trait with a very low variability, even the slightest differences may appear to cause significant differences.

Nordlund et al. (2004) concluded from their studies that fat percentage instead of fat-to-protein ratios should be preferred as indicators of SARA. van Straten et al. (2011) considered test-day fat percentage to be a useful on-farm tool for monitoring cows at risk for claw horn lesions. Results from the present study are inconclusive regarding whether fat percentage or fat-to-protein ratio is a better indicator for the risk of claw lesions. Both parameters lead to similar conclusions.

The synthesis of fat and the synthesis of protein are separate physiological processes; thus, it may complicate the physiological interpretation when inspecting fat-to-protein ratios as opposed to fat percentage, or rather changes in fat percentage. Fat percentage values, or rather their changes, can be taken as one indicator of SARA. Other factors can be indicators of SARA as well (e.g., heat stress, subclinical mastitis, negative energy balance). Subacute ruminal acidosis in turn can contribute to claw horn lesions; hence, concluding from the above, a relationship exists between changes in fat percentage and claw horn lesions. However, this relationship is not a very close one.

For further validation of the results and using a smaller subset of the data, the analysis was repeated with cows that had a hoof-trimming event before d 100 of lactation. Obviously, in this case, only up to 3 test days before trimming could be considered. In summary (data not shown), results were highly similar to the results presented above, although less pronounced. This

Figure 2. Least squares means of test-day milk fat and protein percentages as well as fat-to-protein ratio in the months before diagnosis for heifers with (♦) or without (▲) laminitis-related claw horn disorders; * $P < 0.05$.

similarity could be expected because, as explained in the description of the data, trimming cows within the first half of the lactation had been attempted.

Heritability Estimates

Heritability estimates of hoof disorders are given in Table 6. Estimates ranged between 0.06 (SU) and 0.14 (DD). Because of the size of the data set, standard errors were relatively high. Heritability estimates were in the range of estimates found in the literature reports from similar studies. For the Dutch population, estimates for heifers of 0.07/0.06 (sole hemorrhage), 0.09 (DD), 0.08 (DID), and 0.03 (WLD) have been found

(Stoop et al., 2010; van der Linde et al., 2010). In another study from the Netherlands, van der Waaij et al. (2005) estimated heritabilities for sole hemorrhage, DD, WLD, and SU at 0.08, 0.10, 0.02, and 0.01. For first-lactation Swedish Red, Buch et al. (2011) estimated heritabilities at 0.03 and 0.05 for dermatitis when using a linear model; it was not specified whether it was DD or DID, and sole hemorrhage. Transforming these values to the underlying continuous scale resulted in values of 0.13 and 0.09 and thus were very similar in magnitude to the estimates presented in this study for the dermatitis-like disorders and LAM. Investigations by Koenig et al. (2005) using data from German Holsteins were slightly lower for DD (0.07). The results of

Table 6. Estimates of heritabilities (h^2) for susceptibility to claw disorders from univariate threshold models (mean $\pm$ SE)

Disorder	h^2
Laminitis	0.086 $\pm$ 0.043
Dermatitis digitalis	0.142 $\pm$ 0.048
Dermatitis interdigitalis	0.096 $\pm$ 0.077
White line disease	0.109 $\pm$ 0.054
Sole ulcer	0.064 $\pm$ 0.079

Swalve et al. (2011) showed slightly different estimates of 0.17/0.20, 0.09/0.09, 0.19/0.20, and 0.12/0.12 (logit/probit) for LAM, DD, DID, and WLD. However, in their study, evaluations were based on repeated performances and cows of different parities. Especially the latter effect might explain the differences. Criteria for physical condition were included in neither study.

CONCLUSIONS

With a defined design for a study including field data from contract herds, it was possible to gain more knowledge about the extensive relationships between claw horn lesions, condition status, and fat as well as protein content in milk. Different foot disorders showed varying associations with BW and BCS. This was caused by differences in the etiology of the diseases. Yet an optimum seemed to exist when trying to avoid disorders and diseases of the bovine hoof: the well-conditioned, but not overconditioned, cow. Again, the importance of the management, especially feeding, of young dairy cows was demonstrated. At the same time, the heritability estimates proved that the genetic predisposition of the individual animal for susceptibility to and defense against hoof diseases plays an important role. The magnitude of estimates of heritability in the range of 0.06 to 0.14 suggests that efforts in the field of genetic improvement would be useful to reduce the incidence of hoof diseases. The retrospective analyses of test-day fat percentage as a possible indicator of hoof diseases resulted in only very minor differences between affected and nonaffected cows. Drastic changes in fat percentages within the course of the lactation are indicators of detrimental effects on the health of the cow, which includes hoof health but cannot be used as a single one-to-one indicator for hoof health.

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