Effects of Milk Fever, Ketosis, and Lameness on Milk Yield in Dairy Cows

P. J. RAJALA-SCHULTZ,*,† Y. T. GRÖHN,* and C. E. McCULLOCH‡
*Section of Epidemiology, Department of Population Medicine and Diagnostic Sciences, College of Veterinary Medicine, Cornell University, Ithaca, NY 14853
†Department of Clinical Veterinary Sciences, Faculty of Veterinary Medicine, PO Box 57, FIN-00014 Helsinki University, Finland
‡Biometrics Unit, Department of Statistical Science, Cornell University, Ithaca, NY 14853

ABSTRACT

The effects of milk fever, ketosis, and lameness were studied using data from 23,416 Finnish Ayrshire cows that calved in 1993 and were followed for one lactation (i.e., until culling or the next calving). Monthly test day milk yields were treated as repeated measurements within a cow in a mixed model analysis. Disease index variables were created to relate the timing of a disease to the measures of test day milk. Statistical models for each parity and disease included fixed effects of calving season, stage of lactation, and disease index. An autoregressive correlation structure was used to model the association among the repeated measurements.

The milk yield of cows contracting milk fever was affected for a period of 4 to 6 wk after calving; the loss ranged from 1.1 to 2.9 kg/d, depending on parity and the time elapsed after milk fever diagnosis. Despite the loss, cows with milk fever produced 1.1 to 1.7 kg more milk/d than did healthy cows. Milk yield started to decline 2 to 4 wk before the diagnosis of ketosis and continued to decline for a varying time period after it. The daily milk loss was greatest within the 2 wk after the diagnosis, varying from 3.0 to 5.3 kg/d, depending on parity. Cows in parity 4 or higher were most severely affected by ketosis; the average total loss per cow was 353.4 kg. Lameness also affected milk yield; milk loss of cows diagnosed with foot and leg disorders varied between 1.5 and 2.8 kg/d during the first 2 wk after the diagnosis.
(**Key words**: metabolic diseases, milk yield, repeated measures, mixed model analysis)

INTRODUCTION

Milk fever and ketosis are metabolic diseases of dairy cows that usually occur at the time of calving or early in lactation, respectively. Lameness, however, can occur at any time during the lactation.

The literature gives conflicting results on the effects of these diseases on milk yield. Dohoo and Martin (5) reported that clinical ketosis and foot and leg disorders have a beneficial effect on milk yield and subclinical ketosis have a detrimental effect. Detilleux et al. (4) found milk yield to be affected by ketosis, but, despite that, the ketotic cows yielded more than their healthy herdmates. Many studies (5, 10, 13) have not found any association between milk fever and milk yield. Several statistical approaches have been used to evaluate milk losses caused by diseases. Some of the discrepancies found in the literature with regard to the effects of diseases on milk yield are likely to result from differing statistical methods and different measures of milk yield used.

The purpose of this study was to estimate the effects of milk fever, ketosis, and lameness on milk yield in Finnish Ayrshire cows using monthly test day milk measures in a mixed model analysis.

MATERIALS AND METHODS

Data

The data for this study were from 23,416 Finnish Ayrshire dairy cows that calved during 1993 and were followed until the next calving or culling. The cows were in herds that belonged to the milk registry and the national dairy cow health recording system. These data are a subset of a larger study population of 39,727 Finnish Ayrshire cows, which has been described earlier (11).

The veterinary diagnoses of milk fever, ketosis, and lameness were used for this study. Finnish farmers do not have access to veterinary drugs without supervision of a veterinarian, and so virtually all diseases were diagnosed and treated by a veterinarian during farm visits. Diagnoses were made according to ordinary clinical methods under normal field conditions.

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Only the first occurrence of disease was considered in this study. Calving dates, disease dates, and dates for monthly test day milk sampling were available. Disease occurrences were expressed as lactational incidence risks (8) and were calculated by dividing the number of cows with a particular disease by the total number of cows at risk; disease occurrences are presented as percentages.

Monthly test day milk yields, taken at approximately 30-d intervals, were used to study the effects of milk fever, ketosis, and lameness on milk yield. The lactation was divided into 17 stages: milk records taken within 60 d after calving were grouped by 10-d intervals, records from 61 to 180 d were grouped into 20-d intervals, and records from 181 d and later formed 30-d intervals. Only test day milk yields until 330 d after calving were considered.

Parity had four levels: 1, 2, 3, and 4 or higher. Four calving seasons were defined by 3-mo intervals: winter, December to February; spring, March to May; summer, June to August; and fall, September to November.

Milk fever. Only cows with no diseases during the study lactation (n = 20,983) and such cows with milk fever but no other diseases before and within 4 wk after milk fever diagnosis (n = 1,259) were included in the analyses. Only cows in parities 2, 3, and 4 or higher were considered. To relate the test day milk yields to the time of disease diagnosis, a disease index variable was created for each test day milk yield in order to study the effects of milk fever on milk yield. Two different ways of estimating the milk loss were tested: 1) the milk yield of the healthy cows and 2) the yield of the milk fever cows more than 8 wk after the diagnosis.

The milk fever index variable, when the cow's own yield later in lactation was the reference, was defined as follows: 1 = cow was healthy (i.e., had not been diagnosed with any disease during the lactation), 2 = test day yields collected within 14 d after the diagnosis, 3 = test day yields collected between 15 and 28 d after the diagnosis, 4 = test day yields collected between 29 and 42 d after the diagnosis, 5 = test day yields collected between 43 and 56 d after the diagnosis, and 6 = test day milk yields collected more than 56 d after the milk fever diagnosis (the reference level).

Ketosis. Only cows with no diseases during the study lactation (n = 20,983) and cows with ketosis but no other diseases during the entire study lactation (n = 719) were included in the analyses. In these analyses, the milk yield level prior to disease onset (more than 4 wk before the diagnosis of the disease) of the ketotic cows was used as the reference level.

The ketosis index was defined as follows: 1 = cow was healthy (i.e., had not been diagnosed with any disease during the entire lactation), 2 = test day yields collected between 15 and 28 d before the diagnosis, 3 = test day milk yields collected within 14 d before the diagnosis, 4 = test day yields collected within 14 d after the diagnosis, 5 = test day yields collected between 15 and 28 d after the diagnosis, 6 = test day yields collected between 29 and 42 d after the diagnosis, 7 = test day yields collected later than 42 d after the diagnosis, and 8 = test day milk yields collected more than 28 d before the ketosis diagnosis (the reference level).

Lameness. Only cows with no diseases (n = 20,983) and cows with foot and leg disorders but no other diseases within 4 wk before and after the lameness diagnosis (n = 455) were included in the analyses. To differentiate between cows with and without foot and leg disorders, a lameness index variable was created for each test day milk yield in order to study the effects of lameness on milk yield. The variable was defined as follows: 1 = cow was healthy (i.e., had not been diagnosed with any disease during the lactation), 2 = test day yields collected between 15 and 28 d before the diagnosis, 3 = test day milk yields collected within 14 d before the diagnosis, 4 = test day yields collected within 14 d after the diagnosis, 5 = test day yields collected between 15 and 28 d after the diagnosis, 6 = test day yields collected between 29 and 42 d after the diagnosis, 7 = test day yields collected later than 42 d after the diagnosis, and 8 = test day milk yields collected more than 28 d before the diagnosis (the reference level).

Statistical Analysis

Repeated measurements were present in both space and time. Cows within the same herd were clustered in space, and repeated measurements of daily milk yields of the same cow were correlated in time. What makes the repeated measures analysis distinct from simple linear models is the covariance structure of the observed data. In a typical experiment utilizing repeated measures, two measurements taken at adjacent times are typically more highly correlated than two measurements taken several time points apart (9).

One type of statistical analysis that can be used for repeated measures is based on the mixed model with a special parametric structure for the covariance matrices. This type of methodology has been computationally feasible only in recent years and is applied in PROC MIXED of SAS (9), typically using the REPEATED statement. This procedure was used for these data with the monthly test day milk yields as the outcome variable. A cow usually has approximately 10 monthly test day milk yields recorded during a lactation. Because milk yield measurements from the same lactation for a cow are correlated, it is important to account for this correlation in estimating the effects of disease on milk yield.

In our previous study (12), we compared three commonly used correlation structures (simple, compound symmetry, and first-order autoregressive) and found the first-order autoregressive correlation structure to provide the best fit to these data, based on Akaike's information criterion and Schwartz's Baysian criterion.

In PROC MIXED, the standard linear model is generalized to form a mixed model: $\mathbf{y} = \mathbf{X}\beta + \mathbf{Z}\gamma + \epsilon$ with $\mathrm{Var}(\gamma) = \mathbf{G}$ and $\mathrm{Var}(\epsilon) = \mathbf{R}$, so that $\mathrm{Var}(\mathbf{y}) = \mathbf{ZGZ}' + \mathbf{R}$, where $\mathbf{y}$ = vector of test day milk yields, β = vector of fixed effects, γ = random herd effects, and ϵ = vector of random errors.

A correlation pattern can be modeled in PROC MIXED in two ways, by introducing a correlation pattern in the random effects γ through a nonidentity matrix $\mathbf{G}$ or by an $\mathbf{R}$ matrix so that it equals σ^2 multiplied by some nonidentity matrix.

The effects of milk fever, ketosis, and lameness on test day milk yields were studied separately for each parity (i.e., parities 1, 2, 3, and 4 or higher). For milk fever, the effects were studied also for parities 2 or higher together (pooled data). Calving season, stage of lactation, and disease variables were fixed effects in each model.

RESULTS AND DISCUSSION

The lactational incidence risks (LIR) of milk fever, ketosis, and lameness and the number of cows with these disorders are presented in Table 1. Because the lactational incidence risks of milk fever among parity 1 cows was so low, data on these cows were excluded from the analysis. To avoid the confounding effect of any other disease, only those cows with milk fever and no other diseases before or within 4 wk after the milk fever diagnosis were included in the analysis, even though some information was lost by excluding those other records. For the ketosis analysis, only cows diagnosed with ketosis and no other diseases during the entire lactation were included to avoid the confounding effect of any other diseases. Also, only cows diagnosed with foot and leg disorders that did not have any other diseases within 4 wk before or after the diagnosis were included in the study.

Calving season was a very significant factor in each model for all of the diseases. Cows calving during the fall were the highest producers of milk, and cows calving in spring and summer produced significantly less milk. In most models, cows calving in winter did not significantly ($P > 0.05$) differ from cows calving in fall.

Milk Fever

When the yield of cows with milk fever was compared with that of the healthy cows, milk fever did not have a clear milk-reducing effect in our data. On the contrary, the results suggested that cows contracting milk fever were higher yielding cows. At 2 to 4 wk after onset of the disease, cows in parities 2 or higher (the pooled data) on average yielded 0.9 kg more milk/d; during the next 2 wk, they yielded 1.2 kg more milk/d, and, during the remainder of lactation, they yielded 1.6 kg more milk/d than healthy cows (results not shown). Therefore, the milk yield of the cows with milk fever more than 8 wk after the diagnosis was chosen as the comparison level. Milk yield at this point gives an indication of the yield potential of the cow and what yield would have been from the beginning of lactation had she not contracted milk fever.

TABLE 1. Lactational incidence risks (percentage) of milk fever,[1] ketosis,[2] and lameness[3] and the number of cases of each disease by parity for 23,416 Finnish Ayrshire cows that calved in 1993 and were followed for one lactation (until the next calving or culling).

Disease	Parity 1		Parity 2		Parity 3		Parity 4+		Overall	
	(%)	(no.)	(%)	(no.)	(%)	(no.)	(%)	(no.)	(%)	(no.)
Milk fever	0.2	14	1.1	63	5.7	215	16.7	967	5.7	1259
Ketosis	2.5	178	3.2	182	4.2	157	4.1	202	3.3	719
Lameness	2.5	185	1.3	75	1.7	61	2.8	134	2.1	455

[1]Cows with milk fever and no other diseases before and 4 wk after the diagnosis.

[2]Cows with ketosis and no other diseases during the entire lactation.

[3]Cows with foot and leg disorders and no other diseases within 4 wk before and 4 wk after the lameness diagnosis.

TABLE 2. Effects of milk fever on milk yield (kilograms) by parity for 22,242 Finnish Ayrshire cows that calved in 1993 and were followed for one lactation.[1]

	Parity ≥2		Parity 2		Parity 3		Parity 4+	
Effect[2]	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
0–14 d AD	–1.8***	0.2	–2.7*	1.1	–2.9***	0.5	–1.4***	0.3
15–28 d AD	–1.1***	0.2	1.4	0.9	–1.6**	0.5	–1.0***	0.3
29–42 d AD	–0.5**	0.2	–1.3	0.9	–1.2**	0.4	–0.4	0.2
43–56 d AD	–0.3	0.2	–0.2	0.7	–0.6	0.4	–0.3	0.2
Healthy	–1.6***	0.1	–0.9	0.7	–1.7***	0.3	–1.1***	0.2
Total loss[3]	–47.6		–37.8		–79.8		–33.6	

[1]Yield of the cows with milk fever more than 8 wk after the diagnosis was used as the reference level.

[2]Period when the test day milk sample was collected with respect to the diagnosis of the disease (AD = after diagnosis).

[3]Total loss is the sum of statistically significant daily losses multiplied by the number of days (i.e., 14 d) in each period.

*$P \le 0.05$.

**$P \le 0.01$.

***$P \le 0.001$.

Table 2 presents the results when the cow's own yield was used as the reference level. During the first 2 wk after the diagnosis, cows with milk fever in parities 2 or higher (the pooled data) yielded 1.8 kg less milk/d than they did later in lactation. During the following 2 wk, the loss was 1.1 kg/d, and, during the next 2 wk, it was 0.5 kg/d (Table 2). In general, healthy cows yielded 1.6 kg/d less than cows that contracted milk fever. Cows with milk fever in parity 2 yielded 2.7 kg less milk/d during the first 2 wk than later in the lactation. In parity 3, the losses from milk fever during the three 2-wk periods after calving were 2.9, 1.6, and 1.2 kg/d, chronologically. The oldest cows lost 1.4 kg/d during the first 2 wk after the diagnosis and lost 1.0 kg/d during the following 2 wk. The healthy cows produced 1.1 to 1.7 kg less milk/d than did cows with milk fever later in lactation, depending on parity (Table 2).

Increased milk yield has been found to be a risk factor for milk fever in several studies (1, 2, 6, 7, 11). However, results found in the literature state that milk fever is not associated with milk loss; Rowlands and Lucey (13) and Lucey et al. (10) reported no significant associations between hypocalcemia and milk yield. Also, Deluyker et al. (3) reported no association between milk yield and milk fever. Dohoo and Martin (5) found no direct effect of milk fever on milk yield, but they speculated that a negative association might have been masked by the positive association found between previous milk yield and the occurrence of milk fever.

Probably because of the method used to study the question of milk loss, these studies were not able to show any effect. Because cows with milk fever seem to be higher yielding cows and because the disease occurs so early in lactation, it is difficult to show the milk-reducing effect of the disease. When compared with the yield of the healthy cows, no negative effects as a consequence of milk fever were found; the milk yield just dropped to the level of the healthy cows. If 305-d milk yield is used as a milk measure, cows with milk fever still can yield more than healthy cows, despite having contracted the disease, and no effect is evident. Our method of comparing the milk yield of cows with milk fever to their own yield potential later in lactation, however, enabled us to estimate the milk loss caused by milk fever. Our estimates could still underestimate the true effect of milk fever if the cows had other diseases that caused reduced milk yield more than 8 wk after calving (yield at that time was used as the reference level).

Ketosis

Ketosis had a significant negative effect on milk yield. The milk-reducing effect started even before the diagnosis of clinical ketosis (Table 3), which agrees with the findings of Lucey et al. (10), who reported that milk yield declined for 2 to 4 wk before diagnosis of ketosis. They estimated the total losses in milk yield associated with ketosis to be 60 to 70 kg, which was less than our estimates. In our study, the milk loss continued for at least 2 wk after diagnosis, and the overall loss during the entire lactation (e.g., in parity 1 and in parity 4 or higher) was 126.0 and 535.4 kg, respectively (Table 3). In both of these

TABLE 3. Effects of ketosis on milk yield (kilograms) by parity for 21,702 Finnish Ayrshire cows that calved in 1993 and were followed for one lactation.[1]

	Parity 1		Parity 2		Parity 3		Parity 4+	
Effect[2]	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
28–14 d BD	–1.2*	0.6	–1.5	1.0	–1.2	0.9	–2.1*	0.8
1–14 d BD	–1.7***	0.5	–2.7***	0.8	–1.5*	0.7	–4.9***	0.8
0–14 d AD	–3.0***	0.5	–4.0***	0.9	–3.3***	0.8	–5.3***	0.8
15–28 d AD	–1.5**	0.5	–2.3**	0.9	–0.5	0.8	–2.6***	0.8
28–42 d AD	–1.6**	0.5	–1.4	0.9	–0.2	0.8	–3.2***	0.8
>42 d AD	–0.8	0.5	–1.5	0.8	0.9	0.8	–1.2***	0.8
Healthy	–1.1*	0.5	–1.5	0.8	0.3	0.8	–1.8*	0.8
Total loss[3]	–126.0		–126.0		–67.2		–535.4	

[1]Milk yield of the cows with ketosis more than 4 wk before disease diagnosis was used as the reference level.

[2]Period when the test day milk sample was collected with respect to the diagnosis of the disease (BD = before diagnosis; AD = after diagnosis).

[3]The total loss was calculated assuming a 305-d lactation and ketosis occurring on d 28. Only statistically significant losses within each time period were considered in calculating the total loss.

*$P \leq 0.05$.

**$P \leq 0.01$.

***$P \leq 0.001$.

parity groups, the milk-reducing effect started 4 wk prior to the diagnosis. The daily milk loss was greatest within the first 2 wk after the diagnosis, being 3.0, 4.0, 3.3, and 5.3 kg/d for parities 1, 2, 3, and 4 or higher, respectively. In parity 4 or higher, the milk loss continued for the rest of the lactation, which could be an indication that the energy requirements of the cows were not met. The healthy cows in parity 1 and in parity 4 or higher yielded significantly less than the cows that contracted ketosis; healthy cows in parity 1 yielded on average 1.1 kg less milk/d, and cows in parity 4 or higher yielded 1.8 kg less milk/d than ketotic cows in the same parity. This is in agreement with the results of Detilleux et al. (4), who also reported that ketotic cows yielded more milk over the entire lactation than did the healthy cows. They also reported a significant depression in the lactation curve of the ketotic cows in early lactation.

TABLE 4. Effects of lameness on milk yield (kilograms) by parity for 21,438 Finnish Ayrshire cows that calved in 1993 and were followed for one lactation.[1]

	Parity 1		Parity 2		Parity 3		Parity 4+	
Effect[2]	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
28–14 d BD	–0.3	0.4	–1.0	0.8	0.5	1.0	0.1	0.7
1–14 d BD	–1.5***	0.4	–0.9	1.1	–0.4	0.8	–2.6**	0.8
0–14 d AD	–1.5***	0.4	–0.9	0.9	–2.0	1.1	–2.8***	0.8
15–28 d AD	–1.6***	0.4	–0.5	1.1	–2.2*	0.9	–2.8***	0.8
28–42 d AD	–1.0*	0.5	–0.7	1.0	–0.8	1.1	–1.7*	0.8
>42 d AD	–1.1**	0.4	–0.3	1.0	–0.6	0.9	–0.8	0.7
Healthy	–0.3	0.3	–0.5	0.8	–0.7	0.8	–1.8**	0.7
Total loss[3]	–310.5		. . .		–30.8		–138.6	

[1]Milk yield of cows with foot and leg disorders more than 4 wk before the disease diagnosis was used as the reference level.

[2]Period when the test day milk sample was collected with respect to the diagnosis of the disease (BD = before diagnosis; AD = after diagnosis).

[3]The total loss was calculated assuming a 305-d lactation and lameness occurring on d 52. Only statistically significant losses within each time period were considered in calculating the total loss.

*$P \leq 0.05$.

**$P \leq 0.01$.

***$P \leq 0.001$.

Dohoo and Martin (5), however, reported that a case of ketosis appeared to increase yield by approximately 2.5%, and they attributed that increase to the initial therapy and follow-up therapy after the diagnosis. Another possible, and maybe even more likely, explanation could be that cows with ketosis were higher yielding and simply milked more even after contracting ketosis, as was found in our study. Rowlands and Lucey (13) reported an average significant reduction of 6 to 7% in peak yield in lactations in which the cows had ketosis. There was, however, no overall significant difference in 305-d milk yield. All of these findings indicate that cows with ketosis are, in general, higher yielding and that the milk loss often is only temporary.

Lameness

The lactational incidence risk of lameness (foot and leg disorders) was very low in our data at only 2.1%. Our current data consisted of healthy cows and lame cows that had no other diseases within the 4 wk before and 4 wk after the lameness diagnosis. Thus, we were able to exclude the confounding effect caused by any other diseases occurring close to the lameness diagnosis. We compared the milk yield of cows with foot and leg disorders to their own yield more than 4 wk before the diagnosis. Milk yield of cows in parity 1 began to decline 2 wk before the clinical diagnosis of the disorder, the loss being 1.5 kg/d (Table 4). Within the first 2 wk after the diagnosis, the loss was 1.5 kg/d; during the following 2 wk, the loss was 1.6 kg/d, and, during the following 2 wk, the loss was 1.0 kg/d. The negative effect continued even longer (i.e., for the rest of the lactation), and the loss was 1.1 kg/d.

In parity 2, lameness had a negative effect on milk yield; however, the effect was not significant. The lactational incidence risk of lameness was lowest in parity 2, and a small sample size might partly explain why we were not able to detect significant effects. In parity 3, the loss during the first 2 wk after the diagnosis was 2.0 kg/d ($P < 0.07$) and, during the following 2 wk, it was 2.2 kg/d. In parity 4 or higher, the milk-reducing effect began 2 wk before the diagnosis (2.6 kg/d) and continued for 6 wk after the diagnosis; the loss was 2.8, 2.8, and 1.7 kg/d during the three 2-wk periods following the diagnosis. In parity 4 or higher the healthy cows yielded less milk (1.8 kg/d) than did the cows with foot and leg disorders; among younger cows, there was no significant difference. Dohoo and Martin (5) reported a large positive direct effect of foot and leg disorders on milk yield (expressed as kilograms of milk per day of life); the overall effect represented an increase of approximately 1.6% in milk yield per day of life. Again, this effect could probably be explained by the fact that, in their data, cows with foot and leg disorders were higher yielding cows. Also, Rowlands and Lucey (13) reported that cases of lameness were more common in cows that had higher than average peak milk yields, and Deluyker et al. (3) reported that limping diagnosed within 49 d after calving coincided with higher daily yield during 1 to 5 d postpartum and higher cumulative yield up to 21 d and 49 to 119 d postpartum, which is in agreement with our observation that lame cows in parity 4 or higher produced 1.8 kg more milk/d than did the healthy cows. Our estimates could be underestimating the true effect of lameness if the cows had some other diseases causing reduced milk yield more than 4 wk before the lameness diagnosis.

It should be noted that all of these diseases were recorded by veterinarians. Some minor cases of ketosis and leg and foot disorders might not be recorded if the farmer does not seek veterinary attention for these cows. But, even if some of the cows with these diseases were misclassified as healthy in our study, their proportion in that group was so small that it would not have had a significant effect. In the estimation of milk loss among the diseased cows, however, some overestimation of the milk loss might occur if some minor cases are not included in the data.

CONCLUSIONS

Milk fever affected milk yield for 4 to 6 wk after calving; the loss varied between 1.1 and 2.9 kg/d, depending on parity and the time elapsed after the diagnosis. Cows contracting milk fever were higher yielding than were healthy cows. Ketosis had a negative effect on milk yield; milk yield began to decline 2 to 4 wk before the diagnosis of ketosis, and the milk-reducing effect continued for a varying length of time, depending on parity. The losses were greatest during the 2 wk following the diagnosis (varying from 3.0 to 5.3 kg/d). Also, lameness had a negative effect on milk yield; cows in parity 1 were affected most.

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