Association Between Somatic Cell Count in Early Lactation and Culling of Dairy Heifers Using Cox Frailty Models

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ABSTRACT

The association between somatic cell count (SCC) of dairy heifers in early lactation [SCC_{el}; measured between 5 and 14 d in milk (DIM)] and the culling hazard during the first lactation was studied using Cox frailty models. Udder health problems were the culling reason for 10% of the culled heifers in this study. For each unit increase in the log-transformed SCC_{el} (LnSCC_{el}), the culling hazard increased by 11% [Hazard ratio (HR) = 1.11]. The strength of the association depended on 5 factors. Firstly, the association was stronger when SCC_{el} was recorded after 10 DIM than at an earlier DIM. Secondly, the association was stronger if only culling events for udder disorders were considered (HR = 1.32) instead of all culling events (HR = 1.11). Furthermore, for each unit increase of test-day LnSCC after 14 DIM, modeled as a time-varying covariate, the culling hazard in the first lactation increased by 26% (HR = 1.26). Including LnSCC in the model already containing LnSCC_{el}, reduced the estimate of LnSCC_{el} slightly. Fourth, a higher test-day milk yield, modeled as a time-varying covariate, protected against culling and reduced the magnitude of the effect of LnSCC_{el} as well when taken into account. Finally, the association between LnSCC_{el} and culling was still present, although smaller, in the group of heifers with a second test-day SCC ≤ 50,000 cells/mL.

(Key words: Cox frailty model, culling, dairy heifer, early lactation somatic cell count)

Abbreviation key: HR = hazard ratio, LnSCC = natural log-transformed SCC, LnSCC_{el} = natural log-transformed SCC_{el}, MY = milk yield at test-day (kg; measured after 14 DIM), SCC_{el} = SCC in early lactation (measured between 5 and 14 DIM).

INTRODUCTION

Mastitis is an important culling reason in cows (Beaudeau et al., 1995; Barkema et al., 1998; Bascom and Young, 1998; Gröhn et al., 1998; Seegers et al., 1998; Rajala-Schultz and Gröhn, 1999a, 1999b; Neerhof et al., 2000). Acute mastitis in the first weeks of lactation has a significant effect on culling (Beaudeau et al., 1995; Rajala-Schultz and Gröhn, 1999a). Nearly 11% of heifers that were treated for clinical mastitis before calving or within the first 14 DIM were culled within 1 mo after treatment (Waage et al., 2000). The main culling reason for 96% of these heifers was mastitis. Cows with test-day SCS in the highest classes had almost a 3 times higher rate of culling compared with test-day scores on the average level (Samoré et al., 2003).

Elevated SCC in early lactation (SCC_{el}) in heifers, suggesting presence of IMI around calving, is associated with elevated test-day SCC and higher probabilities of test-day SCC >200,000 cells/mL (De Vlieghe et al., 2004a), and with an increased probability of clinical mastitis during the first lactation (Rupp and Boichard, 2000). In addition, elevated SCC_{el} is associated with lower milk production (Coffey et al., 1986; De Vlieghe et al., 2005). Furthermore, clinical and subclinical mastitis early postpartum have negative effects on reproductive performance (Barker et al., 1998; Schrick et al., 2001). As a result, dairy herds with a large number of heifers calving with infected udder quarters will suffer substantial economical losses. Moreover, elevated SCC_{el} in heifers could be associated with an increased culling hazard during the first lactation, possibly to some extent because of the aforementioned effects. Disease (including mastitis) has direct and indirect effects on culling. The indirect effects may be reflected by, for instance, milk yield (MY) (Gröhn et al., 1997), as most diseases cause a decline in MY, either temporarily or longer lasting (Gröhn et al., 1998). Comparing models with and without MY helps to estimate the direct and indirect effects of mastitis in general on culling (Rajala-Schultz and Gröhn, 1999b). Survival analysis is often

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Table 1. Hierarchy of the data.

Data set ¹	Level	n	Average number per unit at next-higher level	Range
Full	Herd	3192	—	—
	Heifer	13,835	4.3 ²	1–56 ⁴
	Test	114,906	8.3 ³	1–12 ⁵
Sub	Herd	2755	—	—
	Heifer	7596	2.8 ²	1–22 ⁴
	Test	64,054	8.4 ³	1–11 ⁵

¹Full = test-day records between 15 and 365 DIM from 13,835 heifers; Sub = subset of test-day records from heifers with a second test-day SCC (recorded <75 DIM) of $\leq 50,000$ cells/mL.

²Average number of heifers per herd.

³Average number of records per heifer.

⁴Range of heifers per herd.

⁵Range of tests per heifer.

used to assess the effect of covariates that are measured only once (time-independent covariates, e.g., the effect of SCCel in this study). Some covariates, however, are changing over time (e.g., SCC and MY at the different test-days throughout lactation) and can easily be incorporated into the semiparametric Cox models as time-depending or time-varying covariates (Gröhn et al., 1997).

The objectives of the study were 2-fold: 1) to examine the association between SCCel of heifers and culling during the first lactation while accounting for the day of assessment of SCCel and for the variability between herds, and 2) to determine what part of the effect of SCCel on culling acts indirectly through increased test-day SCC and decreased MY, by adjusting the models for test-day SCC and MY, modeled as time-varying covariates.

MATERIALS AND METHODS

Data Set and Data Handling

The DHI data used in the present study are described in detail elsewhere (De Vliegher et al., 2004a). In short, 14,234 heifers belonging to 3264 herds (enrolled in the Belgian DHI program; Flemish Cattle Breeding Association, Oosterzele, Belgium) that calved between January 1, 2000 and December 31, 2000, and of which the first test-day took place between 5 and 14 DIM, were followed until 365 DIM, drying off, or culling. The primary culling reason was recorded by the farmer (low milk production, reproductive disorders, udder disorders, foot/leg problems, behavioral problems, death, and nonspecified reasons). Heifers for which it was unclear whether they were culled or not and heifers belonging to herds that stopped activities during the study period were omitted from further analyses, resulting in data

from 13,835 heifers (97.2% of 14,234) belonging to 3192 herds. In total, the data set contained 114,906 test-day records measured after 14 DIM. A heifer was considered to be culled or censored at its last available test-day. Somatic cell count was measured in composite milk samples collected from 2 successive milkings and was analyzed using the Fossomatic 5000 (Foss Electric, Hillerød, Denmark).

Two data sets were created based on the full data set containing data from 13,835 heifers. The structure of the 2 data sets is given in Table 1. An event was defined as culling for all reasons combined in the first data set (CULLALL_{full}; 3204 events), and as culling for udder disorders only in the second data set (CULLUDD_{full}; 325 events). A similar approach was followed for a subset of data of 7596 heifers with a second test-day SCC (measured after 14 DIM and before 75 DIM) of $\leq 50,000$ cells/mL. In the first data set, an event was defined as culling for all reasons combined (CULLALL_{sub}; 1587 events), and in the second data set an event was defined as culling for udder disorders only (CULLUDD_{sub}; 136 events).

Statistical Analysis

The association between the natural log-transformed SCCel (**LnSCC**el) and the culling hazard was studied by a semiparametric Cox model (Cox, 1972). The Cox model was extended to a frailty model by introducing herd as a random effect to account for the clustering of heifers within herds (Duchateau and Janssens, 2004). The time to culling information for the k th heifer from herd j that was assessed at DIM equal to i was given by (t_{ijk}, δ_{ijk}) , where t_{ijk} represents the time of culling, and δ_{ijk} was equal to 0 if the heifer was censored and to 1 in the case of culling.

Two $\times 7$ different models were fitted using CULLALL_{full} and CULLUDD_{full}, respectively, with breed incorporated as a fixed effect in all models. Both natural log-transformed test-day SCC (**LnSCC**) and test-day MY (measured between 15 and 365 DIM) were considered time-varying covariates when included in the models. To adjust for the fact that LnSCC_{el} was not assessed at the same day after calving for each heifer, the Cox models were stratified according to DIM (5 to 14) on which LnSCC_{el} was measured in the period called “early lactation”. This means that for each DIM value (each stratum) another baseline hazard function was assumed.

In the first model, LnSCC_{el} was introduced assuming a constant effect over the different DIM in early lactation (model 1). In the second model, the same relationship between LnSCC_{el} and the culling hazard was studied, but a different relationship between LnSCC_{el} and

Table 2. Overview of the culling reasons of the 3204 culled heifers out of the total study population of 13,835 Flemish (Belgium) heifers.

Reason for culling	n	% of all heifers	% of culled heifers
Nonspecified reason	1298	9.4	40.5
Reproductive disorders	834	6.0	26.0
Low milk yield	357	2.6	11.1
Udder disorders	325	2.3	10.1
Death	204	1.5	6.4
Lameness and foot/leg defects	162	1.2	5.1
Behavior	24	0.2	0.7
Total	3204	23.2	100.0

the culling hazard was allowed according to DIM on which LnSCC_{el} was recorded (model 2). These 2 models were compared with each other based on the likelihood-ratio test. Models 3 and 4 contained LnSCC and MY, respectively. Models 5 and 6 contained both LnSCC_{el} (as in model 2) and LnSCC, and LnSCC_{el} (as in model 2) and MY, respectively, to evaluate the changes in LnSCC_{el} when the time-varying covariates were included separately. Model 7 was the full model containing LnSCC_{el} (as in model 2), LnSCC, and MY.

Two additional models (similar to model 2) were fitted using CULLALL_{sub} and CULLUDD_{sub}, respectively, to study the association between the LnSCC_{el} and the culling hazard in the group of heifers with a very low second test-day SCC ($\leq 50,000$ cells/mL), suggesting no udder health disorders present at that time.

Hazard ratios (**HR**) with 95% confidence intervals were obtained for all covariates. All models were fitted with S-Plus 6.0 for Windows (Insightful Corp., Seattle, WA).

RESULTS

Descriptive Analysis

Geometric mean SCC_{el} of the 13,835 heifers was 111,000 cells/mL, ranging from 5000 to 25,000,000 cells/mL. In total, 3204 heifers (23.2%) were culled during their first lactation (Table 2). The 2 main specified reasons of culling were reproductive disorders and low MY. In total, 325 heifers (2.3% of all heifers and 10.1% of the cows culled in first lactation) were culled for udder health disorders as the primary reason. No reason was specified in 40.5% of all cullings.

Heifers with a higher SCC_{el} were more at risk for being culled during lactation (Figure 1). For instance, at 100 DIM, 3% of the heifers with a SCC_{el} $\leq 50,000$ cells/mL were culled, whereas 7% of heifers with a SCC_{el} $> 1,000,000$ cells/mL were culled. At 200 DIM, this was 7 and 13%, respectively. The same trends are present in the heifers that were culled for udder disorders (Figure 2), but the differences between the SCC_{el}

levels were smaller. Heifers with a SCC_{el} $> 500,000$ cells/mL were culled earlier in lactation compared with the other heifers (Figure 2). Both Kaplan-Meier graphs present survival until 305 DIM as afterwards too few animals remained at risk.

Cox Models

For each unit increase in the LnSCC_{el}, the culling hazard of 13,835 dairy heifers in the first lactation increased by 11% (HR = 1.11; 95% CI: 1.08 to 1.14) (Table 3, model 1). The model allowing for a different association between LnSCC_{el} and the culling hazard per DIM in early lactation (Table 3, model 2) was significantly better (likelihood ratio test; $\chi^2 = 41.2$, df = 9, $P < 0.001$). An increase in LnSCC_{el} was associated with an increased culling hazard, except for DIM 5. The association was significant from DIM 10 and onwards (except for DIM 11) (Table 3, model 2). The association between LnSCC_{el} and culling was stronger (a HR of 1.32 for each unit increase in LnSCC_{el}) if only culling for udder disorders (CULLUDD_{full}) was considered (Table 4, model 1). Allowing different effects per DIM in early lactation (Table 4, model 2), did not significantly improve the model (Table 4, model 2 vs. 1; likelihood ratio test; $\chi^2 = 12.8$, df = 9, $P = 0.17$), but all HR were > 1 . Black Holstein-Friesian heifers were culled less frequently compared with Belgian White-Blue double-purpose heifers and heifers of unknown breed (Tables 3 and 4, models 1 and 2).

Log-transformed SCC was significantly related to the culling hazard of dairy heifers with an HR of 1.26 for each unit increase in LnSCC (Table 3, model 3). The HR increased to 1.80 when only culling for udder disorders specifically (CULLUDD_{full}) was considered (Table 4, model 3). Introducing LnSCC into the models that already comprised LnSCC_{el} reduced the estimate of LnSCC_{el} at every DIM in early lactation (Tables 3 and 4, model 5 vs. model 2). The reduction was larger when studying the association in heifers that were culled for udder problems.

Higher MY protected heifers against culling (Tables 3 and 4, model 4). The magnitude of LnSCC_{el} at the different DIM in early lactation was slightly reduced when MY was taken into account (Tables 3 and 4, model 6 vs. 2). The changes were smaller compared with the changes due to introducing LnSCC. In addition, incorporating MY into the models took away the breed effect: Black Holstein-Friesian heifers were no longer protected from culling (e.g., Tables 3 and 4, model 4 vs. model 2). The most elaborate model presents the estimates of LnSCC_{el} adjusted for both LnSCC and MY (Tables 3 and 4, model 7).

Figure 1. Kaplan-Meier graph of culling of heifers for all reasons (until 305 DIM) with an SCC in early lactation (SCC_{el}, measured between 5 and 14 DIM, $\times 1000$ cells/mL) of 0 to 50 ($\circ$), 51 to 200 ($\triangle$), 201 to 500 ($+$), 501 to 1000 ($\times$), and >1000 cells/mL ($\diamond$).

Studying the association between LnSCC_{el} and culling in heifers with a second test-day SCC $\leq 50,000$ cells/mL (CULLALL_{sub} and CULLUDD_{sub}) revealed that, although the association was smaller, an elevated SCC_{el} was, in general, still associated with a higher culling hazard, especially for SCC_{el} measured in the second part of the period called “early lactation” (Table 5).

DISCUSSION

In this study, Cox frailty models were used to study the association between SCC_{el} and the culling of heifers belonging to different herds. The influence of test-day SCC and MY on the magnitude of SCC_{el} was assessed. The results of this study add further knowledge on the negative impact of heifer mastitis reflected by elevated SCC_{el} as an indicator of subclinical mastitis around calving. Reproduction was the primary culling reason in our study; production was second, and mastitis third, which corresponds with the findings of Bascom and Young (1998).

Because SCC_{el} decreases substantially in the first 2 wk after calving (Dohoo, 1993; Laevens et al., 1997; De Vliegher et al., 2001, 2004a, b), models that stratified for day of assessment of SCC_{el} were fitted. This implied that no conclusion on a DIM effect on the culling hazard could be drawn, but as no biologically relevant effect could be expected, this was not a problem. Based on our previous findings, an effect was expected related to the infection dynamics during the early lactation period as discussed earlier (De Vliegher et al., 2004a; De Vliegher et al., 2005). The most prevalent group of mastitis pathogens associated with IMI in heifers at parturition are the coagulase-negative staphylococci that are transient in nature (Oliver and Mitchell, 1983), probably because they are colonizing the teat canal rather than the mammary gland and are washed out during milking. In addition, a high rate of spontaneous IMI elimination occurs (Oliver and Jayarao, 1997). *Staphylococcus aureus*, on the other hand, can also be associated with IMI in heifers at calving (Fox et al., 1995), but tends to persist in lactation (Roberson et al., 1994).

Figure 2. Kaplan-Meier graph of culling of heifers for udder health disorders (until 305 DIM) with an SCC in early lactation (SCC_{el}, measured between 5 and 14 DIM, $\times 1000$ cells/mL) of 0 to 50 ($\circ$), 51 to 200 ($\triangle$), 201 to 500 ($+$), 501 to 1000 ($\times$), and >1000 cells/mL ($\diamond$).

Some of the factors that needed to be evaluated or adjusted for (e.g., test-day SCC and test-day MY) change over the course of lactation. To assess their immediate effect, they were introduced as time-varying covariates, because summary measures (e.g., lactation average SCC or MY) are not able to determine the effect of a covariate throughout lactation (Gröhn et al., 1997). Furthermore, the clustering effects due to the fact that heifers belong to different herds had to be taken into account by introducing a random herd effect in the Cox model, rather than including herd as a fixed effect because the individual farm is not of interest by itself (Duchateau and Janssens, 2004).

Considering only the heifers that were culled for udder health reasons (CULLUDD) vs. all culled heifers (CULLALL) increased the magnitude of association between SCC_{el} and SCC, and the culling hazard. This is comprehensible, as the effect is not diluted by the other reasons why heifers are culled. We wanted to present both approaches because the DHI program only allows farmers to identify one culling reason per heifer, whereas farmers usually consider many factors when

deciding to cull an animal (Bascom and Young, 1998). In addition, for 40.5% of the culled heifers, no specific reason was available, although some of them were probably culled because of udder health problems. Still, even when considering all culling reasons, an elevated SCC_{el} predicted a higher culling hazard, confirming the negative economic consequences of heifer mastitis at freshening, even though the HR was only significantly >1 when recorded after 9 DIM. Confidence intervals around the HR were wider for heifers culled for udder health disorders (CULLUDD) compared with all culled heifers (CULLALL). Therefore, fewer HR significantly differed from 1, which also occurred in the analyses in the subsets of data (CULLALL_{sub} and CULLUDD_{sub}). This is comprehensible as the power in survival analysis is a function of the number of events and not of the number of observations (Freedman, 1982).

Beaudeau et al. (1995) included the potential 305-d mature equivalent milk production rather than actual MY in the survival models when studying the effect of disease on culling in French dairy cows. This approach avoided inclusion of part of the impact of disease on

Table 3. Association between log-transformed SCC in early lactation (LnSCC_{el}, measured between 5 and 14 DIM, × 1000 cells/mL), log-transformed test-day SCC (LnSCC, × 1000 cells/mL) and test-day milk yield (MY), and the hazard of being culled for all reasons in 13,835 dairy heifers (CULLALL_{full}).

Variable	Model 1			Model 2			Model 3			Model 4		
	HR ¹	95% CI ²		HR ¹	95% CI ²		HR ¹	95% CI ²		HR ¹	95% CI ²	
LnSCC _{el} ³	1.107	1.076	1.140	—	—	—	—	—	—	—	—	—
LnSCC _{el} DIM 5 ⁴	—	—	—	0.967	0.869	1.076	—	—	—	—	—	—
LnSCC _{el} DIM 6	—	—	—	1.031	0.947	1.122	—	—	—	—	—	—
LnSCC _{el} DIM 7	—	—	—	1.070	0.979	1.170	—	—	—	—	—	—
LnSCC _{el} DIM 8	—	—	—	1.064	0.967	1.171	—	—	—	—	—	—
LnSCC _{el} DIM 9	—	—	—	1.068	0.970	1.176	—	—	—	—	—	—
LnSCC _{el} DIM 10	—	—	—	1.146	1.045	1.256	—	—	—	—	—	—
LnSCC _{el} DIM 11	—	—	—	1.083	0.988	1.186	—	—	—	—	—	—
LnSCC _{el} DIM 12	—	—	—	1.265	1.159	1.380	—	—	—	—	—	—
LnSCC _{el} DIM 13	—	—	—	1.175	1.080	1.278	—	—	—	—	—	—
LnSCC _{el} DIM 14	—	—	—	1.192	1.092	1.301	—	—	—	—	—	—
MY ⁵	—	—	—	—	—	—	—	—	—	0.900	0.892	0.909
LnSCC ⁵	—	—	—	—	—	—	1.261	1.223	1.301	—	—	—
Breed												
Breed 1 ⁶	1.000	—	—	1.000	—	—	1.000	—	—	1.000	—	—
Breed 2 ⁷	1.143	0.975	1.341	1.144	0.975	1.342	1.136	0.968	1.334	1.098	0.927	1.300
RHF ⁸	0.963	0.840	1.103	0.958	0.836	1.098	0.996	0.869	1.143	1.124	0.972	1.301
BHF ⁹	0.731	0.642	0.832	0.731	0.642	0.832	0.769	0.675	0.877	1.073	0.931	1.238

Variable	Model 5			Model 6			Model 7		
	HR ¹	95% CI ²		HR ¹	95% CI ²		HR ¹	95% CI ²	
LnSCC _{el} ³	—	—	—	—	—	—	—	—	—
LnSCC _{el} DIM 5 ⁴	0.946	0.849	1.054	0.952	0.855	1.060	0.932	0.837	1.039
LnSCC _{el} DIM 6	0.997	0.915	1.086	1.024	0.940	1.115	0.995	0.913	1.085
LnSCC _{el} DIM 7	1.031	0.942	1.129	1.044	0.954	1.143	1.010	0.922	1.107
LnSCC _{el} DIM 8	1.023	0.928	1.127	1.054	0.956	1.162	1.020	0.924	1.126
LnSCC _{el} DIM 9	1.018	0.923	1.123	1.061	0.962	1.169	1.018	0.922	1.123
LnSCC _{el} DIM 10	1.108	1.009	1.216	1.136	1.034	1.247	1.105	1.005	1.215
LnSCC _{el} DIM 11	1.033	0.941	1.134	1.054	0.960	1.157	1.016	0.925	1.116
LnSCC _{el} DIM 12	1.191	1.090	1.302	1.246	1.138	1.363	1.186	1.083	1.300
LnSCC _{el} DIM 13	1.112	1.020	1.211	1.146	1.052	1.250	1.096	1.004	1.196
LnSCC _{el} DIM 14	1.123	1.027	1.227	1.151	1.053	1.257	1.097	1.003	1.200
MY ⁵	—	—	—	0.903	0.894	0.911	0.906	0.898	0.915
LnSCC ⁵	1.240	1.201	1.281	—	—	—	1.204	1.165	1.245
Breed									
Breed 1 ⁶	1.000	—	—	1.000	—	—	1.000	—	—
Breed 2 ⁷	1.145	0.975	1.345	1.106	0.934	1.309	1.104	0.931	1.308
RHF ⁸	0.988	0.861	1.133	1.114	0.963	1.289	1.126	0.972	1.304
BHF ⁹	0.765	0.671	0.872	1.063	0.921	1.226	1.078	0.934	1.245

¹HR = Hazard ratio.²95% confidence interval around HR.³Assuming a constant effect of LnSCC_{el} over the different DIM in early lactation.⁴Allowing different effects of LnSCC_{el} over the different DIM in early lactation.⁵Time-varying covariate.⁶Belgian White-Blue double-purpose heifers and heifers of unknown breed.⁷Meuse-Rhine-Yssel, Red, Red and White, Jersey.⁸Red Holstein-Friesian.⁹Black Holstein-Friesian.

culling through their effect on cumulative milk production. However, high-yielding cows, even if they are diseased, are more likely to be kept in the herd (Gröhn et al., 1998). Comparing models with and without MY, can therefore help to estimate the direct and indirect effects of mastitis or disease in general on culling (Rajala-Schultz and Gröhn, 1999b). Hence, MY was in-

cluded in the models to find out whether this changed the magnitude of the effect of SCC_{el} on culling. Acute mastitis in the first month of lactation had a significant effect on culling throughout lactation (Rajala-Schultz and Gröhn, 1999a), but adding MY to the model, in general, reduced the effect (Rajala-Schultz and Gröhn, 1999b). The same was true in our study, indicating that

Table 4. Association between log-transformed SCC in early lactation (LnSCC_{el}, measured between 5 and 14 DIM, × 1000 cells/mL), log-transformed test-day SCC (LnSCC, × 1000 cells/mL) and test-day milk yield (MY), and the hazard of being culled for udder health reasons in 13,835 dairy heifers (CULLUDD_{full}).

Variable	Model 1			Model 2			Model 3			Model 4		
	HR ¹	95% CI ²		HR ¹	95% CI ²		HR ¹	95% CI ²		HR ¹	95% CI ²	
LnSCC _{el} ³	1.325	1.219	1.440	—	—	—	—	—	—	—	—	—
LnSCC _{el} DIM 5 ⁴	—	—	—	1.055	0.754	1.476	—	—	—	—	—	—
LnSCC _{el} DIM 6	—	—	—	1.379	1.092	1.741	—	—	—	—	—	—
LnSCC _{el} DIM 7	—	—	—	1.081	0.830	1.408	—	—	—	—	—	—
LnSCC _{el} DIM 8	—	—	—	1.169	0.891	1.535	—	—	—	—	—	—
LnSCC _{el} DIM 9	—	—	—	1.255	0.919	1.714	—	—	—	—	—	—
LnSCC _{el} DIM 10	—	—	—	1.393	1.016	1.909	—	—	—	—	—	—
LnSCC _{el} DIM 11	—	—	—	1.323	1.039	1.683	—	—	—	—	—	—
LnSCC _{el} DIM 12	—	—	—	1.582	1.250	2.001	—	—	—	—	—	—
LnSCC _{el} DIM 13	—	—	—	1.522	1.211	1.914	—	—	—	—	—	—
LnSCC _{el} DIM 14	—	—	—	1.402	1.079	1.822	—	—	—	—	—	—
MY ⁵	—	—	—	—	—	—	—	—	—	0.917	0.893	0.941
LnSCC ⁵	—	—	—	—	—	—	1.799	1.659	1.952	—	—	—
Breed												
Breed 1 ⁶	1.000	—	—	1.000	—	—	1.000	—	—	1.000	—	—
Breed 2 ⁷	1.183	0.697	2.008	1.209	0.712	2.053	1.212	0.712	2.064	1.216	0.708	2.090
RHF ⁸	1.246	0.798	1.945	1.260	0.807	1.971	1.319	0.843	2.068	1.490	0.938	2.367
BHF ⁹	0.964	0.630	1.477	0.979	0.639	1.502	1.058	0.688	1.628	1.391	0.883	2.194

Variable	Model 5			Model 6			Model 7		
	HR ¹	95% CI ²		HR ¹	95% CI ²		HR ¹	95% CI ²	
LnSCC _{el} ³	—	—	—	—	—	—	—	—	—
LnSCC _{el} DIM 5 ⁴	0.991	0.705	1.394	1.040	0.746	1.448	0.981	0.700	1.374
LnSCC _{el} DIM 6	1.262	0.992	1.606	1.366	1.082	1.723	1.252	0.984	1.593
LnSCC _{el} DIM 7	0.977	0.742	1.285	1.060	0.813	1.382	0.959	0.728	1.261
LnSCC _{el} DIM 8	1.065	0.806	1.407	1.169	0.891	1.534	1.070	0.810	1.413
LnSCC _{el} DIM 9	1.094	0.792	1.510	1.244	0.912	1.695	1.085	0.787	1.495
LnSCC _{el} DIM 10	1.320	0.950	1.835	1.377	1.004	1.889	1.316	0.948	1.828
LnSCC _{el} DIM 11	1.167	0.906	1.504	1.301	1.021	1.658	1.155	0.896	1.488
LnSCC _{el} DIM 12	1.351	1.057	1.727	1.544	1.219	1.995	1.336	1.045	1.708
LnSCC _{el} DIM 13	1.330	1.047	1.689	1.478	1.175	1.859	1.304	1.026	1.656
LnSCC _{el} DIM 14	1.187	0.904	1.557	1.358	1.046	1.764	1.165	0.887	1.529
MY ⁵	—	—	—	0.921	0.897	0.946	0.934	0.910	0.959
LnSCC ⁵	1.738	1.597	1.892	—	—	—	1.711	1.570	1.865
Breed									
Breed 1 ⁶	1.000	—	—	1.000	—	—	1.000	—	—
Breed 2 ⁷	1.222	0.716	2.086	1.233	0.717	2.121	1.243	0.719	2.149
RHF ⁸	1.336	0.851	2.097	1.508	0.948	2.397	1.549	0.970	2.475
BHF ⁹	1.072	0.696	1.652	1.401	0.887	2.211	1.439	0.907	2.282

¹HR = Hazard ratio.²95% confidence interval around HR.³Assuming a constant effect of LnSCC_{el} over the different DIM in early lactation.⁴Allowing different effects of LnSCC_{el} over the different DIM in early lactation.⁵Time-varying covariate.⁶Belgian White-Blue double-purpose heifers and heifers of unknown breed.⁷Meuse-Rhine-Yssel, Red, Red and White, Jersey.⁸Red Holstein-Friesian.⁹Black Holstein-Friesian.

a small part of the effect of an elevated SCC_{el} on test-day SCC was mediated through MY. Moreover, introducing MY in the models influenced the breed effect. In the models without MY, Black Holstein-Friesian were protected from culling, but this effect was due to their higher MY. According to Rajala-Schultz and Gröhn (1999b), the influence of MY on the culling decision also

depends on the lactation stage. We, however, did not distinguish whether the effect differed with differing stages of lactation, as this was not the primary aim of the study.

Test-day SCC was even more associated with culling than was SCC_{el}. Fitting a model with both LnSCC_{el} and LnSCC showed that part of the LnSCC_{el} effect

Table 5. Association between log-transformed SCC in early lactation (LnSCC_{el}, measured between 5 and 14 DIM, $\times 1000$ cells/mL), and the hazard of being culled for all reasons (CULLALL_{sub}), and for udder health reasons (CULLUDD_{sub}) in 7596 dairy heifers.

Variable	CULLALL _{sub}			CULLUDD _{sub}		
	HR ¹	95% CI ²		HR ¹	95% CI ²	
LnSCC _{el} DIM 5 ³	0.884	0.744	1.051	0.970	0.546	1.722
LnSCC _{el} DIM 6	0.942	0.829	1.071	1.015	0.637	1.615
LnSCC _{el} DIM 7	1.145	1.002	1.308	0.887	0.529	1.485
LnSCC _{el} DIM 8	1.064	0.919	1.231	1.219	0.856	1.739
LnSCC _{el} DIM 9	0.936	0.792	1.106	0.698	0.328	1.484
LnSCC _{el} DIM 10	1.103	0.955	1.273	1.781	1.027	3.090
LnSCC _{el} DIM 11	0.951	0.806	1.122	1.106	0.716	1.709
LnSCC _{el} DIM 12	1.327	1.157	1.521	1.185	0.716	1.961
LnSCC _{el} DIM 13	1.127	0.975	1.301	1.381	0.949	2.008
LnSCC _{el} DIM 14	1.102	0.940	1.293	1.096	0.646	1.860
Breed						
Breed 1 ⁴	1.000	—	—	1.000	—	—
Breed 2 ⁵	1.442	1.145	1.816	1.988	0.880	4.483
RHF ⁶	1.098	0.897	1.344	1.467	0.702	3.066
BHF ⁷	0.823	0.678	0.998	1.105	0.543	2.252

¹HR = Hazard ratio.²95% confidence interval around HR.³Allowing different effects of LnSCC_{el} over the different DIM in early lactation.⁴Belgian White-Blue double-purpose heifers and heifers of unknown breed.⁵Meuse-Rhine-Yssel, Red, Red and White, Jersey.⁶Red Holstein-Friesian.⁷Black Holstein-Friesian.

acted through the associated test-day SCC. This was not unexpected as an elevated SCC_{el} increases the odds on elevated test-day SCC (De Vlieghe et al., 2004a). Fitting a model containing LnSCC_{el}, LnSCC, and MY results in estimates for LnSCC_{el} that take into account the SCC effect and adjusts for the protective MY effect. Elevated SCC_{el} is associated with elevated test-day SCC and lower MY, thus part of the association between SCC_{el} and culling was mediated through SCC and MY.

Heifers with excellent udder health at the second test-day but with an elevated SCC_{el} were still more at risk for being culled in their first lactation compared with heifers with an equally low second-test-day SCC but a lower SCC_{el}. Most probably this finding is related to the fact that the latter heifers will have fewer test-day SCC >200,000 cells/mL (De Vlieghe et al., 2004a) and will out-produce the heifers with the higher SCC_{el} (De Vlieghe et al., 2005). This suggests that prevention against elevated SCC_{el}, especially in the second part of the early lactation period (as we defined it), should be preferred over treating an elevated SCC_{el}. Additionally, some of the heifers with (sub)clinical mastitis in early lactation will lose milk production in the affected quarter(s) and will consequently have a low second test-day SCC.

In this data set, no heifers were culled before 32 DIM. This does not reflect the actual situation and is caused by the way the data were collected and handled: only

heifers of which the first test-day SCC was measured between 5 and 14 DIM in the year 2000 ($n = 14,766$) and of which additional test-day SCC were available ($n = 14,234$; selection procedure outlined in De Vlieghe et al., 2004a) were used. Therefore, no heifers that were culled within the first month of lactation were present in the data set. This has resulted in an underestimation of the effect of peripartum udder health problems on the hazard of culling.

The culling decision process is complex and very farmer-, herd-, and time-specific. This is especially true under a quota system (as implemented in Belgium), forcing the farmer to take culling decisions depending on the level of expected fulfillment of the quota. This study ignored some of the points in the complex decision of the farmer as the required herd and time-level information was not available. Economic calculations and implementation of new preventive measures would in addition require cow-specific values. Future studies should collect this information and combine it with data from other studies looking at the association between udder health in early lactation in heifers and udder health (both clinical and subclinical mastitis), production, and fertility in the first and following lactations.

CONCLUSIONS

Heifers with elevated SCC_{el} were at an increased risk of being culled during first lactation. Part of the

effect was associated with the consequential elevation of test-day SCC and suppression of test-day MY. High-yielding heifers were, on average, protected against culling, even if their SCCel was elevated. The association between LnSCC_{el} and culling was still present, although smaller, in heifers with a second test-day SCC $\leq 50,000$ cells/mL, suggesting that prevention rather than cure of an elevated SCC_{el} is needed.

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