Impact of Early Lactation Somatic Cell Count in Heifers on Milk Yield Over the First Lactation

S. De Vlieghe,¹ H. W. Barkema,² H. Stryhn,² G. Opsomer,¹ and A. de Kruif¹

¹Department of Reproduction, Obstetrics, and Herd Health, Faculty of Veterinary Medicine, Ghent University, Merelbeke, Belgium

²Department of Health Management, Atlantic Veterinary College, University of Prince Edward Island, Charlottetown, Canada

ABSTRACT

The objective of this study was to estimate the impact of somatic cell count (SCC) in early lactation (SCC_{el}) [measured between 5 to 14 d in milk (DIM)] of dairy heifers on test-day milk yield (MY) during the first lactation.

In total, 117,496 four-weekly test-day records of 14,243 heifers were used. A multilevel regression analysis, which included test-day SCC among the explanatory variables, revealed that an increase by one unit of the natural log-transformed SCC_{el} (LnSCC_{el}) was on average associated with a decrease in MY of 0.13 kg/d later in lactation. As an example, a heifer with an SCC_{el} of 50,000 cells/mL measured at 10 DIM was estimated to produce 119 and 155 kg more milk during its first lactation than heifers with a SCC_{el} of 500,000 and 1,000,000 cells/mL, respectively. When not accounting for test-day SCC, the effect of LnSCC_{el} on MY was larger, indicating that part of the negative impact of elevated SCC_{el} was associated with elevated test-day SCC later in lactation.

Furthermore, an elevated SCC_{el} at 14 DIM had a larger impact than an equally elevated SCC_{el} measured at an earlier DIM. In addition, the negative effect of an elevated SCC_{el} remained present during almost the entire first lactation in a subgroup of heifers with a second test-day SCC ≤50,000 cells/mL, suggesting that prevention rather than cure of an elevated SCC_{el} should be preferred.

This study stresses the importance of heifers having low SCC_{el}, as an elevated SCC_{el} will negatively affect milk production during the first lactation, probably via impairment of mammary function and, to a smaller extent, via elevated test-day SCC later in lactation.

(Key words: dairy heifer, early lactation, milk yield, somatic cell count)

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

INTRODUCTION

Heifer mastitis is a well-known problem. Many studies have reported a high prevalence of IMI in heifers around calving (Oliver and Mitchell, 1983; Pankey et al., 1991; Oliver et al., 1992; Roberson et al., 1994; Myllys, 1995; Aarestrup and Jensen, 1997; Oliver et al., 2003). More than 27% of 14,766 Belgian dairy heifers had an SCC in early lactation (SCC_{el}) >200,000 cells/mL, suggesting they had an IMI during the peripartum period (De Vlieghe et al., 2004a). Coagulase-negative staphylococci are responsible for the majority of the IMI in nonlactating and freshly calved heifers, but *Staphylococcus aureus* and environmental pathogens may also play a role (Oliver and Mitchell, 1983; Pankey et al., 1991; Oliver et al., 1992; Roberson et al., 1994; Myllys, 1995; Aarestrup and Jensen, 1997; Oliver et al., 2003).

Intramammary infection at parturition, particularly when caused by a major pathogen, will result in an increased SCC at that moment (Barkema et al., 1999). Heifers with an elevated SCC_{el} on average have elevated test-day SCC, are more at risk for having test-day SCC >200,000 cells/mL (De Vlieghe et al., 2004a), and have an increased probability of clinical mastitis (Rupp and Boichard, 2000). Future milk production can be compromised as well (Oliver and Jayarao, 1997).

The negative association between test-day SCC and milk yield has been addressed in some recent studies: the individual milk yield loss in heifers has been estimated at 1.29 kg/d for each unit increase in the log₁₀ SCC (Koldewei et al., 1999). In lactating heifers without clinical mastitis, the reduction in milk yield was 0.30, 0.61, and 1.09 kg when SCC was 100,000, 200,000, and 600,000 cells/mL, respectively (Hortet et al., 1999). In organic dairy herds, heifers had a production loss of 0.20 kg/d of energy-corrected milk with each 2-fold

Received July 27, 2004.

Accepted November 3, 2004.

Corresponding author: Sarne De Vlieghe; e-mail: Sarne.Devlieghe@UGent.be.

Table 1. Descriptive statistics of milk yield (kg/d) throughout the first lactation.

Dataset		n	Average	SD	Min	Max
Full ¹	Test-season					
	January–March	28,871	23.2	5.3	1.3	47.2
	April–June	37,039	22.9	5.2	0.9	45.4
	July–September	22,504	21.9	5.1	1.3	43.5
	October–December	29,082	22.3	5.1	1.2	44.6
	Breed					
	Belgian White-Blue and unknown breed	11,175	19.3	6.8	0.9	47.2
	MRY, ² Red, Red and White, and Jersey	11,682	19.6	4.3	5.8	40.7
	Red Holstein-Friesian	32,890	21.9	4.4	6.7	42.8
	Black Holstein-Friesian	61,749	24.3	4.8	5.2	47.0
	Total	117,496	22.7	5.2	0.9	47.2
Sub ³	Test-season					
	January–March	16,258	23.7	5.1	1.8	47.0
	April–June	20,808	23.3	5.0	1.4	45.1
	July–September	12,422	22.4	4.8	1.7	41.4
	October–December	15,970	22.8	4.9	1.6	44.6
	Breed					
	Belgian White-Blue and unknown breed	5595	20.3	5.9	1.4	40.0
	MRY, Red, Red and White, and Jersey	6230	19.8	4.2	6.9	40.7
	Red Holstein-Friesian	18,156	22.2	4.3	6.9	40.9
	Black Holstein-Friesian	35,477	24.6	4.7	9.3	47.0
	Total	65,458	23.1	5.0	1.4	47.0

¹Milk yield between 15 and 365 DIM from 14,234 heifers (full dataset).

²MRY = Meuse-Rhine-Yssel.

³Milk yield between 15 and 365 DIM from 7807 heifers with a second test-day SCC $\leq 50,000$ cells/mL (subset of data).

increase in SCC between 100,000 and 1,500,000 cells/mL (Bennedsgaard et al., 2003). The association between first test-day SCC and SCC later in lactation was investigated by Coffey et al. (1986): heifers with a first test-day SCC <100,000, 100,000 to 400,000, and >400,000 cells/mL produced 6452, 6050, and 5696 kg during first lactation, respectively. Kirk et al. (1996), on the other hand, found that IMI with minor pathogens in heifers had no effect on average milk production during early to middle lactation. However, only one herd was included in that study.

The primary objective of the present study was to estimate the impact of SCCel on milk yield in the first lactation using multilevel regression analysis, taking into account the day of assessment of SCCel. The study accompanies a previous study (De Vlieghe et al., 2004a) on the impact of SCCel on test-day SCC in the first lactation, based on the same data set. The present analysis extends that analysis by focusing on milk yield, and by investigating both the direct and indirect effects of elevated SCCel, while accounting for the hierarchical structure of the data.

MATERIALS AND METHODS

Initial Data Set and Data Handling

The data used in this study are described elsewhere (De Vlieghe et al., 2004a). In short, approximately

monthly milk recordings (≥ 5 DIM) from 2000 and 2001 of all heifers of all Flemish (Belgium) dairy herds enrolled in the DHI program (Flemish Cattle Breeding Association, Oosterzele, Belgium) were used, including: SCC and milk yield on test-day (**MY**) (kg of milk), breed, DIM, and date of measurement.

Heifers were included if their first test-day in 2000 occurred between 5 and 14 DIM. In total, 117,496 test-day records (full data set) from the first lactation (measured after 14 DIM) were available from 14,234 heifers belonging to 3264 herds. A subset of data was created by selecting heifers with a second test-day SCC (measured after 14 and before 75 DIM) $\leq 50,000$ cells/mL, resulting in 65,458 test-day records from 7807 heifers on 2827 herds.

Statistical Analyses

The statistical analyses aimed at quantifying the effect of SCC in early lactation (measured between 5 and 14 DIM) on MY during the first lactation. A natural logarithmic transformation of SCC (**LnSCC**) and SCCel (**LnSCC_{el}**) was used (De Vlieghe et al., 2004a).

For analysis of the repeated measurements of each heifer, both the full and subset of data were split into 12 subsets referred to as “30-d DIM intervals” (15 to 45, 46 to 75, 76 to 105 ... DIM), reflecting the monthly milk recordings. These intervals were analyzed sepa-

Figure 1. Average milk yield (kg/d) during first lactation from 14,234 (full data set) dairy heifers, stratified by SCC in early lactation (SCC_{cel}, $\times 1000$ cells/mL), 0 to 50 (□), 51 to 200 (■), 201 to 500 (△), 501 to 1000 (▲), and > 1000 cells/mL (○).

ately, except that no analysis was performed for the first two 30-d DIM intervals from the subset of data because selection of animals was based on the measurements within those 2 intervals. To account for multiple testing of the same hypotheses in the 30-d DIM intervals, all *P* values were multiplied by the number of intervals analyzed [Bonferroni correction, see De VliegHER et al. (2004a) for discussion and justification of the analytical approach].

Multilevel linear regression models (one model per 30-d DIM interval) were used to analyze MY as the outcome variable. The models included random effects for herds and heifers, the latter to account for a small number of heifers with 2 test recordings within the same 30-d interval [except for the first (15 to 45 DIM) and 12th (345 to 365 DIM) intervals]. All random effects and error terms were assumed normally distributed. The full model included regression terms for LnSCC_{cel} (predictor of main interest), DIM (between 5 and 14, the day of assessment of LnSCC_{cel}), and the categorical variables test-season and breed (4 levels each, as listed in Table 1). Moreover, the model included interaction terms between LnSCC_{cel} and the predictors DIM and breed, as well as a quadratic term for LnSCC_{cel} and its interaction with DIM. All models were fitted with and without LnSCC as predictor, which allowed studying

changes in the estimate of LnSCC_{cel} when including LnSCC in the model, and helped to estimate the direct and indirect effects of LnSCC_{cel}. The continuous predictors were centered by subtracting their overall mean. After the assumptions of the full model had been evaluated using the residuals, the interaction terms were tested and were removed when nonsignificant (likelihood-ratio test). To facilitate comparison of models for different 30-d DIM intervals, a main effect was kept in all models as soon as it was significant in one 30-d DIM interval.

The distribution of variance of MY at the hierarchical levels (test, heifer, and herd) was assessed for the null-models (without fixed effects). The proportion of variation explained by the fixed effects was calculated as one minus the ratio of the total variance of the final model and the total variance of the null model (Snijders and Bosker, 1999).

Predicted cumulative production between 15 and 365 DIM was calculated for Black-Holstein heifers by multiplying the daily average predicted MY per 30-d DIM interval with 30 (20 for the last interval) and summing up these values over all 30-d DIM intervals. An average test-season effect was assumed.

All analyses were carried out using the MLwiN software, version 1.2 (Rasbash et al., 2000). The significance level for all analyses was set at *P* ≤ 0.05.

Table 2. Final multilevel linear regression models per 30-d DIM intervals describing milk yield (kg/d) during first lactation (between 15 and 365 DIM) in 2000 and 2001 from 14,234 dairy heifers from 3264 herds, accounting for log-transformed test-day SCC (full dataset).

Variables	30-d DIM interval											
	15 to 45			46 to 75			76 to 105			106 to 135		
	β	SE	P^1	β	SE	P^1	β	SE	P^1	β	SE	P^1
Intercept	22.205	0.198		22.634	0.179		22.288	0.170		21.726	0.167	
LnSCC _{cel} ^{2,10,11}	-0.251	0.036	<0.001	-0.163	0.033	<0.001	-0.144	0.033	<0.001	-0.138	0.033	<0.001
DIM ^{3,10,11}	0.063	0.015	<0.001	0.022	0.014	0.028	0.032	0.014	0.003	0.004	0.014	0.027
LnSCC ^{4,10}	-0.183	0.038	<0.001	-0.130	0.028	<0.001	-0.060	0.024	NS	-0.136	0.024	<0.001
Season			<0.001			<0.001			<0.001			<0.001
Apr–Jun	Ref.	...		Ref.	...		Ref.	...		Ref.	...	
Jan–Mar	0.533	0.144		-0.099	0.107		-0.257	0.077		-0.291	0.067	
Jul–Sep	-1.002	0.185		-1.108	0.137		-0.795	0.115		-0.561	0.094	
Oct–Dec	-0.774	0.139		-1.111	0.109		-0.748	0.089		-0.488	0.083	
Breed			<0.001			<0.001			<0.001			<0.001
Breed1 ⁵	Ref.	...		Ref.	...		Ref.	...		Ref.	...	
Breed2 ⁶	-0.180	0.208		-0.068	0.201		-0.144	0.207		-0.058	0.205	
RHF ⁷	0.878	0.179		0.928	0.173		0.929	0.178		0.946	0.177	
BHF ⁸	2.603	0.167		2.677	0.162		2.795	0.166		2.902	0.166	
LnSCC _{cel} × DIM ⁹	-0.039	0.011	0.007	-0.034	0.011	0.021	-0.036	0.011	0.009	-0.038	0.011	0.006
	136 to 165			166 to 195			196 to 225			226 to 255		
	β	SE	P^1	β	SE	P^1	β	SE	P^1	β	SE	P^1
Intercept	21.499	0.160		21.340	0.162		20.966	0.154		20.586	0.152	
LnSCC _{cel} ^{2,10,11}	-0.123	0.032	<0.001	-0.117	0.032	<0.001	-0.095	0.031	0.004	-0.126	0.030	<0.001
DIM ^{3,10,11}	-0.010	0.013	NS	-0.005	0.014	NS	-0.002	0.013	NS	-0.006	0.013	NS
LnSCC ^{4,10}	-0.114	0.025	<0.001	-0.088	0.021	<0.001	-0.127	0.023	<0.001	-0.123	0.022	<0.001
Season			<0.001			<0.001			<0.001			<0.001
Apr–Jun	Ref.	...		Ref.	...		Ref.	...		Ref.	...	
Jan–Mar	-0.123	0.054		-0.132	0.056		-0.101	0.056		-0.219	0.072	
Jul–Sep	-0.518	0.078		-0.498	0.063		-0.303	0.045		-0.230	0.047	
Oct–Dec	-0.727	0.093		-1.202	0.098		-0.935	0.078		-0.781	0.075	
Breed			<0.001			<0.001			<0.001			<0.001
Breed1 ⁵	Ref.	...		Ref.	...		Ref.	...		Ref.	...	
Breed2 ⁶	-0.388	0.199		-0.536	0.202		-0.470	0.193		-0.535	0.191	
RHF ⁷	0.771	0.172		0.541	0.174		0.533	0.166		0.571	0.164	
BHF ⁸	2.778	0.161		2.612	0.164		2.514	0.156		2.564	0.153	
LnSCC _{cel} × DIM ⁹	-0.025	0.011	NS	-0.026	0.011	NS	-0.028	0.010	NS	-0.025	0.010	NS
	256 to 285			286 to 315			316 to 345			346 to 365		
	β	SE	P^1	β	SE	P^1	β	SE	P^1	β	SE	P^1
Intercept	20.528	0.154		20.269	0.168		19.788	0.213		18.671	0.378	
LnSCC _{cel} ^{2,10,11}	-0.088	0.030	0.008	-0.143	0.033	<0.001	-0.088	0.041	NS	-0.125	0.067	NS
DIM ^{3,10,11}	0.004	0.013	NS	-0.021	0.014	NS	-0.012	0.017	NS	-0.039	0.028	NS
LnSCC ^{4,10}	-0.132	0.022	<0.001	-0.157	0.026	<0.001	-0.206	0.036	<0.001	-0.365	0.078	<0.001
Season			<0.001			<0.001			<0.001			<0.001
Apr–Jun	Ref.	...		Ref.	...		Ref.	...		Ref.	...	
Jan–Mar	-1.235	0.110		-1.117	0.107		-0.923	0.142		-0.313	0.318	
Jul–Sep	-0.324	0.045		-0.312	0.046		0.079	0.100		1.324	0.278	
Oct–Dec	-0.869	0.070		-0.779	0.066		-0.426	0.110		0.839	0.276	
Breed			<0.001			<0.001			<0.001			<0.001
Breed1 ⁵	Ref.	...		Ref.	...		Ref.	...		Ref.	...	
Breed2 ⁶	-0.644	0.192		-0.752	0.212		-0.949	0.260		-0.774	0.412	
RHF ⁷	0.420	0.166		0.470	0.181		0.627	0.217		0.667	0.336	
BHF ⁸	2.494	0.155		2.533	0.169		2.791	0.200		2.777	0.312	
LnSCC _{cel} × DIM ⁹	-0.027	0.010	NS	-0.023	0.011	NS	-0.014	0.014	NS	-0.021	0.021	NS

¹Bonferroni corrected P values (original values multiplied by 12).²Log-transformed SCC in early lactation (between 5 and 14 DIM) (×1000 cells/mL).³Day of assessment of LnSCC_{cel}.⁴Log-transformed SCC at test day (×1000 cells/mL).⁵Belgian White-Blue double-purpose heifers and heifers of unknown breed.⁶Meuse-Rhine-Yssel, Red, Red and White, Jersey.⁷Red Holstein-Friesian.⁸Black Holstein-Friesian.⁹Interaction term between LnSCC_{cel} and DIM.¹⁰Centered by subtracting the mean value (LnSCC_{cel} = 4.7; DIM = 9.5, LnSCC = 4.3). See text for details.¹¹ P values correspond to test of both main effect and interaction.

RESULTS

Descriptive Analysis of SCCel and MY

Geometric mean SCCel of the 14,234 selected heifers was 112,000 cells/mL, ranging from 5000 to 25,000,000 cells/mL. More descriptive statistics on SCCel are presented elsewhere (De VliegHer et al., 2004a).

Average MY between 15 and 365 DIM was 22.7 kg/d, ranging from 0.9 to 47.2 kg/d (Table 1). The interquartile range was 6.7 kg. Black Holstein-Friesians had the highest and the Belgian White Blue dual-purpose heifers and heifers of unknown breed had the lowest milk production. Small differences were present between test-seasons (Table 1). Average MY was 23.5 kg/d in the 15 to 45 30-d DIM interval, and increased to 23.8 kg/d in the 46 to 75 interval, after which MY gradually decreased to 21 kg/d at the end of the lactation (345 to 365 DIM).

Of the 14,234 heifers, 55% had a second test-day SCC $\leq 50,000$ cells/mL and the 7807 heifers within this sub data set had an average MY 0.4 kg higher than all heifers (Table 1). Table 1 also shows differences between breeds and test-seasons.

Effect of SCCel on Test-Day MY

Milk yield stratified by 5 SCCel-classes is presented in Figure 1. Heifers having an SCCel $\leq 50,000$ cells/mL produced on average 0.26 kg/d more during the subsequent test-days compared with heifers starting their first lactation with a SCCel between 51,000 and 200,000 cells/mL. This difference was on average 1.44 kg/d for heifers in the lowest SCCel class when compared with heifers with an SCCel $> 1,000,000$ cells/mL. In general, differences between SCCel classes became smaller toward the end of the lactation.

Regression coefficients of LnSCC_{el} on MY corrected for DIM, breed, season, and LnSCC are presented in Table 2. On average, if LnSCC_{el} of a heifer was one unit higher than for another heifer, MY was 0.25, 0.16, and 0.14 kg/d lower in the first, second, and third 30-d DIM intervals, respectively. This interpretation assumes LnSCC_{el} of the 2 heifers to be measured at the same, theoretical DIM of 9.5 (mean value between 5 and 14). The size of the effect decreased throughout the lactation (smaller impact in the later 30-d DIM intervals). Furthermore, the interaction between LnSCC_{el} and DIM was significant in some of the 30-d DIM intervals, indicating that the impact of LnSCC_{el} on MY depended on when it was measured in early lactation. As an example, for a recording at DIM 12, the effect in the first 30-d DIM interval would be $-0.251 + [-0.039 \times (12 - 9.5)] = -0.35$ kg/d, whereas if the recording took place at DIM 7, the effect would be -0.15

kg/d. This LnSCC_{el} effect throughout the whole lactation comparing heifers differing by one unit calculated at 7, 9.5, and 12 DIM is illustrated in Figure 2. The impact of an elevated LnSCC_{el} measured at 12 DIM was higher than that of an equally elevated LnSCC_{el} at 7 DIM. Predicting the cumulative milk production of heifers with different SCCel values (50,000, 200,000, 500,000, and 1,000,000 cells/mL) measured between 5 and 14 DIM also demonstrated this (Figure 3). A higher SCCel was always associated with lower production, but the predicted differences were smaller for heifers with different SCCel values measured at DIM 5 compared with heifers with different SCCel values recorded at a later DIM.

Test-day MY was significantly associated with season and breed. Black-Holstein heifers out-produced the other breeds (Table 2). The effect of LnSCC_{el} on MY did not differ between breeds, as the interaction term between LnSCC_{el} and breed was never significant.

Fitting models that did not include LnSCC as predictor variable resulted in larger estimates of LnSCC_{el}. On average, if LnSCC_{el} of one heifer was one unit higher than for another heifer, MY was 0.32, 0.20, and 0.16 kg/d lower in the first, second, and third 30-d DIM intervals, respectively. As before, this interpretation assumes LnSCC_{el} of the 2 heifers to be measured at the same, theoretical DIM of 9.5. The model-based estimates for LnSCC_{el} (not correcting for LnSCC) in all 30-d DIM intervals are presented in Figure 2. The estimates of all other predictor variables are not presented because the changes were minimal.

Heifers with a second test-day SCC of $\leq 50,000$ cells/mL (data subset, Figure 4) had higher test-day MY compared with heifers in the full data set (Figure 1), and the differences between heifers in different SCCel classes were smaller (Figures 1 and 3), corresponding to smaller regression coefficients of LnSCC_{el} on MY (Table 3, left columns). However, the effect of LnSCC_{el} (at DIM 9.5) was reasonably constant at -0.1 kg/d and significant until 255 DIM. As before, fitting models without LnSCC as a predictor variable resulted in larger LnSCC_{el} estimates (Table 3, right columns).

Approximately 55 and 44% of the variation in MY resided at the herd and heifer level, respectively, with a very small proportion left at the test level. Between 10.3 (46 to 75 DIM) and 16.2% (316 to 345 DIM) of the variation was explained by adding the fixed effects.

In some 30-d DIM intervals, the quadratic term of LnSCC_{el} was significant, indicating that (at least in those intervals) the association between MY and LnSCC_{el} was nonlinear. We decided however, to present only models without the quadratic term, making interpretation of the models more straightforward. This approach was also preferred in an earlier study (De

Figure 2. Regression coefficients for log-transformed SCC in early lactation (LnSCC_{el}, ×1000 cells/mL) per 30-d DIM interval measured at 7 (◇), 9.5 (□), and 12 (△) DIM. Estimates are based on the final multilevel linear regression models describing milk yield (kg/d) during first lactation (between 15 and 365 DIM) in 2000 and 2001 from 14,234 dairy heifers from 3264 herds, accounting for log-transformed test-day SCC (LnSCC, ×1000 cells/mL). Regression coefficients for LnSCC_{el} (×1000 cells/mL) per 30-d DIM interval measured at 9.5, but based on the final multilevel linear regression models not accounting for log-transformed test-day SCC (×1000 cells/mL) are indicated by the dashed line (■).

Figure 3. Estimated cumulative milk production between 15 and 365 DIM from Black-Holstein heifers with different SCC in early lactation (×1000 cells/mL) measured at different DIM, based on the final models accounting for log-transformed test-day SCC.

Vlieghe et al., 2004a) and was based on inspection of graphs presenting the linear and nonlinear relation showing a good agreement.

DISCUSSION

Monthly milk-recording data were used to investigate the impact of SCC_{el}, measured in the first 2 wk after calving, on MY in the subsequent first lactation. The day on which SCC_{el} was assessed was taken into account. Elevated SCC_{el} was associated with a reduced MY and a lower cumulative milk production during the first lactation, resulting in suboptimal revenues for the farmer.

Prevalence of IMI is high in peripartum dairy heifers (Oliver and Mitchell, 1983; Pankey et al., 1991; Oliver et al., 1992; Roberson et al., 1994; Myllys, 1995; Aarestrup and Jensen, 1997; Oliver et al., 2003). Coagulase-negative staphylococci are the predominant organisms causing these IMI, but the number of CNS infections decreases markedly in early lactation (Oliver and Mitchell, 1983; Matthews et al., 1992; Myllys, 1995; Kirk et al., 1996; Barkema et al., 1999), suggesting that most

Figure 4. Average milk yield (kg/kg) during first lactation from 7807 heifers with a second test-day SCC $\leq 50,000$ cells/mL, stratified by SCC in early lactation (SCC_{el}, $\times 1000$ cells/mL), 0 to 50 (□), 51 to 200 (■), 201 to 500 (△), 501 to 1000 (▲), and >1000 cells/mL (○).

teat canal colonizations and subclinical IMI due to CNS around calving will not become chronic (Myllys, 1995). However, duration of IMI varies among CNS species. *Staphylococcus chromogenes*, the most prevalent CNS before parturition, disappears from most quarters shortly after freshening, whereas *Staphylococcus simulans* persists into lactation (Aarestrup and Jensen, 1997). Intramammary infections caused by major mastitis pathogens will not cure as easily as IMI caused by CNS (Oliver and Mitchell, 1983; Roberson et al., 1994). For instance, 50% of *Staph. aureus* IMI in heifers persist for at least 1 mo (Roberson et al., 1994). In addition, the incidence rate of clinical mastitis in heifers is very high during the first 14 d of lactation (Barkema et al., 1998). Bacteriological culture results during early lactation were not available in our study. Rather, SCC_{el} was used to reflect udder health of the heifers shortly after calving and to study the effect on future milk production. This approach allowed for a quantification of the impact based on a large number of animals.

An elevated SCC_{el} shortly after calving was associated with lower test-day MY in the subsequent months. This is not surprising as mammary tissue of quarters infected with *Staph. aureus* is less developed and has greater leukocyte infiltration compared with uninfected quarters (Trinidad et al., 1990). Quarters infected with

CNS also exhibit greater leukocyte infiltration and a higher proportion of interalveolar stroma compared with uninfected controls. Furthermore, presence of IMI in unbred heifers increases leukocytosis in the mammary gland and reduces secretory activity in heifers, suggesting an adverse effect on future milk production (Trinidad et al., 1990). Our study showed that an elevated SCC_{el}, reflecting the inflammation process of the mammary gland parenchyma caused by mastitis pathogens present at calving, has indeed a detrimental impact on the lactational milk production. Lower milk production is the consequence of the pathogenic effect of bacterial virulence factors and damage caused by PMNL and other inflammatory cells on the mammary parenchyma. Part of the negative effect of an increased SCC_{el} on MY in this study was associated with elevation of subsequent test-day SCC. This was demonstrated by comparing models with and without LnSCC as a predictor variable: LnSCC, when incorporated into the models, took away part of the effect of LnSCC_{el}. This was not unexpected, as, based on the same data set, we demonstrated earlier that heifers with elevated LnSCC_{el} will on the average, have elevated test-day SCC later in lactation, and will have more test-day SCC $>200,000$ cell/mL, suggesting the presence of subclinical mastitis (De Vliegher et al., 2004a).

Table 3. Regression coefficients for log-transformed SCC in early lactation (LnSCC_{el}, ×1000 cells/mL) per 30-d DIM interval based on the final multilevel linear regression models [with and without log-transformed test-day SCC (LnSCC, ×1000 cells/mL)] describing milk yield (kg/d) during first lactation (between 76 and 365 DIM) from 7807 dairy heifers from 2878 herds (sub dataset).

30-d DIM interval	Models with LnSCC ¹			Models without LnSCC		
	β	SE	P^2	β	SE	P^2
76 to 105	-0.128	0.050	<0.001	-0.137	0.050	<0.001
106 to 135	-0.100	0.050	0.008	-0.113	0.050	0.004
136 to 165	-0.104	0.049	0.048	-0.113	0.048	0.029
166 to 195	-0.048	0.050	0.019	-0.056	0.050	0.014
196 to 225	-0.094	0.047	0.031	-0.110	0.047	0.013
226 to 255	-0.097	0.046	0.059	-0.110	0.046	0.028
256 to 285	-0.066	0.047	NS	-0.079	0.047	NS
286 to 315	-0.121	0.052	0.022	-0.141	0.051	0.007
316 to 345	-0.116	0.064	NS	-0.135	0.064	NS
346 to 365	-0.050	0.107	NS	-0.083	0.107	NS

¹Centered by subtracting the mean value (3.9). See text for details.

²Bonferroni corrected P values (original values multiplied by 10), corresponding to test of both main effect and interaction.

Heifers with a first test-day SCC <100,000 cells/mL, produced approximately 400 and 750 kg more than heifers with a first test-day SCC of 100,000 to 400,000 and >400,000 cells/mL, respectively (Coffey et al., 1986). These differences were larger than in our study, but the comparison is difficult as, for instance, it was not clear when the first test-day SCC were recorded in that study. Furthermore, culling bias may have influenced our results because heifers with udder disorders at parturition are more likely to be culled during their first lactation (Waage et al., 2000). This has probably resulted in an overall underestimation of the effect of an elevated SCC_{el} on MY throughout the first lactation and explains the smaller impact of LnSCC_{el} on MY in the later 30-d DIM intervals.

Day of measurement of the first test-day SCC was not part of the evaluation by Coffey et al. (1986), although the statistically significant interaction between SCC_{el} and DIM in our study indicates that it is important to take this into consideration. The biology behind this finding is associated with the decreasing SCC_{el} between 5 and 14 DIM (Dohoo, 1993; Laevens et al., 1997; Barkema et al., 1999; De Vlieghe et al., 2001), reflecting the declining prevalence of CNS-infected quarters in early lactation and an increasing MY (Schepers et al., 1997). In the previous study, the effect of SCC_{el} on test-day SCC also depended on the day of assessment in early lactation (De Vlieghe et al., 2004a). As mentioned earlier, a high proportion of the IMI caused by CNS is cleared once the heifer starts lactating because of their transient nature, but SCC in recovered quarters will take some time to return to a normal level. A heifer with an elevated SCC_{el} at 5 DIM may have had quarters recovering from CNS infections, resulting in a more or less normal SCC_{el} level within

the next few days. Such a heifer will not produce much less milk than a heifer with a very low SCC_{el} at 5 DIM. This hypothesis is supported by the findings from a study in which samples from 339 heifers were cultured in early lactation in a large dairy herd with a low prevalence of major mastitis pathogens. Intramammary infection caused by minor pathogens did not have a significant effect on milk production (Kirk et al., 1996). On the other hand, an SCC_{el} that was still elevated 2 wk after calving had a larger impact on future milk production. Possibly, heifers with an elevated SCC_{el} later in the early postpartum period suffered from a persistent IMI (e.g., caused by *Staph. aureus*), already present before calving, or had been infected early postpartum, resulting in elevated SCC_{el} until 14 DIM and thereafter. The damaging effect of an *Staph. aureus* infection will be more extensive compared with a CNS IMI simply because *Staph. aureus* possesses a wider “arsenal” of virulence factors that allows this pathogen to cause more damage and, therefore, higher and extended SCC values. However, more studies are needed to elucidate these hypotheses and bacteriological cultures should be included.

The results from this study should motivate dairy farmers to try to reduce the number of heifers with an elevated SCC_{el}. Farmers invest time and money in raising their young stock, but their heifers will not produce according to expectations if they freshen with an elevated SCC_{el}. Therefore, farmers should focus on prevention of IMI before and at calving rather than on treatment of IMI after calving as the negative effect of an elevated SCC_{el} on MY was still present, although smaller in size, in heifers with a second test-day SCC ≤50,000 cells/mL. This means that even if a heifer has a low second test-day SCC it will, on average, be out-

produced by a heifer with an equally low SCC at the second test-day but with a lower SCCel. Prevention of IMI prepartum in heifers remains difficult because our knowledge of the pathogenesis is still limited, even though some herd- and heifer-associated factors related to heifer mastitis have been identified (Fox et al., 1995; Myllys and Rautala, 1995; Østerås et al., 1997; Waage et al., 1998; Bareille et al., 2000; Waage et al., 2001; De VliegHER et al., 2004b).

Multilevel modeling can aid in estimating the relative importance of herd and individual factors with a view to targeting animal health interventions more effectively (McDermott and Schukken, 1994). Although management is key in mastitis prevention, focusing on differences between heifers rather than differences between herds is necessary to reduce the prevalence of heifers with an elevated SCCel as the vast majority of the variation in SCCel was present at the heifer level, leaving more room for improvement compared with the herd level (De VliegHER et al., 2004b). The findings for SCCel do not apply for MY because approximately 55% of the unexplained variation in MY was present at the herd level, indicating that farmers have more room to improve production in heifers by applying better management practices.

CONCLUSIONS

Elevated SCCel in heifers is associated with a decreased lactational production. The cumulative milk loss over the whole first lactation can be high: a heifer with an SCCel of 500,000 cells/mL measured at 10 DIM, for instance, produced 119 kg less during first lactation than a heifer with an SCCel of 50,000 cells/mL also measured at 10 DIM. The effect is, however, modified by the day of assessment of SCCel: an elevated SCCel at 5 DIM is less consequential than an equally high SCCel at 14 DIM. The suboptimal production could be partially explained by detrimental effects of IMI at calving on the secretory tissue but our study indicated that part of the effect was associated with permanently elevated SCC throughout lactation. The financial losses for a farm with a high prevalence of heifers with elevated SCCel can be large, resulting in suboptimal revenues.

ACKNOWLEDGMENTS

The authors would like to thank E. De Mûelenaere and the Flemish Cattle Breeding Association (Oosterzele, Belgium) for providing us with the milk-recording data and to Elanco Belgium for supporting this study financially.

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