Interaction of Somatic Cell Count and Quarter Milk Flow Patterns

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ABSTRACT

Milk flow parameters at udder and quarter levels were studied in relation to somatic cell count (SCC) and other risk factors for mastitis (bimodality, duration of decline, and duration of overmilking phase). Thirty-eight Holstein cows in their first to sixth lactations were investigated during 10 mo of lactation. Monthly milk samples were collected for SCC during morning milking. Quarter and udder milk flows were recorded daily. A cow was included if one quarter was found to have an SCC higher than 200×10^3 cells/mL. A total of 3,262 quarter milk flow curves and 804 udder milk flow curves from 22 cows (6 primiparous and 16 multiparous) were selected and evaluated. Selected data for milk flow profiles in relation to SCC represented 5 consecutive morning milkings around the time of milk sampling (sampling on d 3). A total of 661 milk samples were analyzed. At both the udder and quarter levels milk yield was reduced in groups with increased SCC. Quarters with high SCC ($>500 \times 10^3$ cells/mL) had lower peak flow rate and longer overmilking phases compared with quarters with low SCC ($<200 \times 10^3$ cells/mL). There was a tendency for a longer duration of the decline phase in quarters with high SCC but no effect was observed at the udder level. There were longer declines in bimodal milk flows at the quarter, but not at the udder, level. Also, quarters with bimodality had longer overmilking phases. The duration of the decline phases at the quarter level influenced all measured parameters except the duration of the increase phase. The quarters with a longer duration of the decline phase (≥ 80 s) had greater SCC and peak flow rate but had lower milk yield compared with quarters with a shorter duration of the decline phase (<27 s). Duration of the overmilking phase influenced all measured parameters except SCC. We conclude that for good udder health, the duration of the decline phase at the quarter level should be considered

for milking parameters and udder preparation before milking.

Key words: milk flow, quarter, somatic cell

INTRODUCTION

Milk flow patterns provide important information about the cow's response to milking conditions. The milk flow pattern and milk yield also indicate physiological factors and stages such as parity, stage of lactation (Mayer et al., 1991), readiness for milking (Rasmussen et al., 1990; Tančín et al., 2006b), udder health status (Perez-Guzman et al., 1986; Naumann et al., 1998), and factors causing poor milk removal (Marnet and McKusick, 2001; Tančín and Bruckmaier, 2001). Recently, greater emphasis has been placed on quarter milk flow patterns because they offer more biological information that is needed for improving machine milking and the welfare of cows (Tančín et al., 2006a).

The pattern of milk flow has 4 phases of flow intensity [increase, plateau, decline, and blind (overmilking)]. The duration of increase phase at both the udder and quarter levels is primarily related to time from udder preparation to milking (Wellnitz et al., 1999). Insufficient udder preparation before milking results in the bimodal type of milk flow during the increase phase. The milk flow at udder and quarter levels differs in the plateau and decline phases. The duration of the plateau phase of whole udder milk flow is when all quarters are milked together. When one or more quarters are emptied in a stepwise manner or continuous flow declines in all quarters simultaneously, then the decline phase of the udder milk flow starts (Mačuhová et al., 2003). At a single quarter level, the duration of the plateau phase depends on the amount of available milk in the cistern, the intensity of its continuous filling from alveoli and the milkability (Tančín et al., 2006a). The decline phase starts when the rate of refilling of the cistern by alveolar milk declines or ceases or when the refilling rate is lower than the milk flow rate through the teat canal.

Somatic cell count is an indicator of mastitis (Pyorala, 2003) and its relationship to the parameters of milk flow pattern could be important for improvement of

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milking conditions. The duration of the decline phase for udder milk flow was positively correlated with SCC, perhaps implying a negative effect of overmilking individual quarters within the udder (Naumann et al., 1998). Overmilking the udder creates a high risk for poor udder health (Natzke et al., 1978), although no correlation between the duration of overmilking of an earlier milked-out quarter and SCC was found (Wellnitz et al., 1999). It is also known that cows with a high peak flow rate are more sensitive to mastitis (Grindal and Hillerton, 1991). Few studies have addressed the quarter milk flow pattern or milkability and SCC (Wellnitz et al., 1999; Naumann and Fahr, 2000; Kohler and Kaufmann, 2003; Weiss et al., 2004). We have found that quarters with longer decline phases had greater SCC (Tančin et al., 2002) and quarters with a high peak flow had a longer decline phase (Tančin et al., 2003, 2006a). It is important to know if there are quarter milk flow characteristics that can be used for earlier identification of health problems or if specific milk flow characteristics are risk factors for mastitis.

The aim of the present study was to test the hypothesis that the duration of the decline and overmilking phases and the peak flow rate are factors that affect SCC. An experiment was conducted to study milk flow characteristics at the udder and quarter levels in relation to SCC and other mastitis risk factors (bimodality and duration of decline and overmilking phases).

MATERIALS AND METHODS

Animals and Milking Procedure

The study was conducted at the experimental farm “De Vijf Roeden” in the Netherlands in 1999 and 2000. Thirty-eight Holstein cows (first to sixth lactation) were investigated during 10 mo of lactation. Cows were free of clinical symptoms of mastitis. Cows received a mixed ration consisting of 70% grass silage and 30% whole-crop corn silage on a DM basis. Some concentrate was added to the mixture so that it was sufficient for a milk yield of 26 to 27 kg/d per cow. Additional concentrate was fed in the milking parlor with a minimum of 1 kg/d and more depending on the level of the daily milk yield above 27 kg.

Cows were milked twice a day at 0530 and 1530 h in a 2 × 3 open autotandem milking parlor. Premilking udder preparation lasted 8 to 10 s per udder and consisted of forestripping, cleaning, and drying with a dry paper towel. A cluster was attached immediately after preparation. Milking and pulsation vacuum was set at 43 kPa; the pulsation ratio was 65:35 at a rate of 60 cycles/min. Quarter milk was collected in receiver jars that were mounted in a basement below the milking stalls. The height difference between the milking clus-

ter on the udder and the bottom of the receiver jar was about 180 cm. The cluster was automatically removed 4 s after the whole udder milk flow declined below 0.3 kg/min for a period of 6 s. The milk weights were converted to a milk flow rate profile for each individual quarter as described (Tančin et al., 2006a). The milk samples for SCC were collected monthly at the end of a milking from the quarter milk receiver jars. The milk in the receiver jar was mixed before sample collection by admitting air at the bottom of the jar for at least 15 s. Quarter and udder milk flows were recorded daily. Milk flow profiles in relation to SCC represented 5 consecutive morning milkings around the time of milk sampling. The milk sampling for SCC was performed on d 3. A total of 661 milk samples were analyzed. The cow was included in the statistical analysis if one quarter was found to have an SCC $>200 \times 10^3$ cells/mL. There were 3,262 quarter milk flow curves and 804 udder milk curves flow from 22 cows (6 primiparous and 16 multiparous).

Statistical Methods

The milk yield and the milk flow measures at quarter and udder levels were analyzed by the mixed model procedure of SAS (version 8.2; SAS Institute, 2001). The results of SCC were log transformed. In the statistical model for udder data (model 1, below) the effects of parity, stage of lactation, peak flow rate, SCC, and bimodality were tested. In the model for quarter traits (model 2, below), one factor was added—position of single quarters.

The type of milk flow was divided into 2 groups: milk flow with or without bimodality. Stage of lactation was divided into 3 periods: less than 100 DIM, between 100 and 200 DIM, and over 200 DIM. Parity included 2 groups of cows: primiparous ($n = 6$) and multiparous (≥ 2 lactations, $n = 16$). The peak flow rate represents 3 groups of cows with different average maximum udder peak flow rates (**PFR**) during the whole lactation: low (<3.2 kg/min, $n = 4$ cows), middle (between 3.2 and 4.2 kg/min, $n = 13$ cows), and high (>4.2 kg/min, $n = 5$ cows). Based on SCC, 3 groups of quarters were created: low ($<200 \times 10^3$ cells/mL, $n = 2,669$ quarters), middle (between 200×10^3 and 500×10^3 cells/mL, $n = 291$ quarters), and high ($>500 \times 10^3$ cells/mL, $n = 291$ quarters). Whole udders based on SCC of their individual quarters were divided into 3 groups on the same principle as described previously: low ($n = 353$ udders), middle ($n = 210$ udders), and high ($n = 241$ udders). The quarters with different durations of overmilking phase were divided into 3 groups: <15 s, between 16 and 99 s, and ≥ 100 s. The quarters with different duration of decline phase were divided into 3 groups: <27 s, between 28

Table 1. Least squares means ($\pm$ SEM) of measured variables at udder and quarter level in relation to the level of SCC

Variable	Udder level SCC, $\times 10^5$ cells/mL				Quarter level SCC, $\times 10^5$ cells/mL			
	<2	2 to 5	>5	<i>P</i> <	<2	2 to 5	>5	<i>P</i> <
Number	353	210	241		2,669	291	302	
Milk yield, kg	18.61 $\pm$ 0.47 ^a	17.61 $\pm$ 0.45 ^b	17.30 $\pm$ 0.47 ^b	0.0001	4.29 $\pm$ 0.14 ^a	4.01 $\pm$ 0.14 ^b	3.61 $\pm$ 0.14 ^c	0.0001
Milking time, s	463 $\pm$ 15 ^a	429 $\pm$ 14 ^b	434 $\pm$ 15 ^b	0.0001	372 $\pm$ 13 ^a	362 $\pm$ 12 ^b	367 $\pm$ 13 ^b	0.0001
Peak flow, kg/min	3.79 $\pm$ 0.21 ^a	3.94 $\pm$ 0.21 ^b	3.79 $\pm$ 0.21 ^a	0.0009	0.95 $\pm$ 0.05 ^a	0.91 $\pm$ 0.04 ^a	0.83 $\pm$ 0.05 ^b	0.0001
Milk yield in 1st min, g	1,661 $\pm$ 104	1,732 $\pm$ 105	1,582 $\pm$ 105	0.1114	422 $\pm$ 21 ^a	398 $\pm$ 23 ^b	320 $\pm$ 23 ^c	0.0001
Phase increase, s	83 $\pm$ 4	81 $\pm$ 4	83 $\pm$ 4	0.8106	75 $\pm$ 4	75 $\pm$ 4	75 $\pm$ 4	0.9159
Phase plateau, s	212 $\pm$ 10 ^a	172 $\pm$ 10 ^b	178 $\pm$ 10 ^b	0.0001	231 $\pm$ 16	221 $\pm$ 16	228 $\pm$ 16	0.0875
Phase of decline, s	169 $\pm$ 10	171 $\pm$ 10	168 $\pm$ 10	0.8996	63 $\pm$ 6	67 $\pm$ 6	70 $\pm$ 6	0.0578
Phase of overmilking, s					66 $\pm$ 6 ^a	62 $\pm$ 7 ^a	79 $\pm$ 7 ^b	0.0042

^{a-c}Least squares means within a row of evaluated level without a common superscript letter were significantly different at $P < 0.05$.

and 79 s, and ≥ 80 s. The quarter factor represented the position of individual quarters; that is front left, front right, rear left, and rear right.

The statistical model can be written in the following form:

Udder data

$$y_{ijklp} = \mu + PAR_i + STAGE_j + PEAK_k + SCC_l \quad [1] \\ + BIMO_z + u_p + e_{ijklzp}$$

Quarter data

$$y_{ijklmnop} = \mu + PAR_i + STAGE_j + PEAK_k + SCC_l \quad [2] \\ + DEC_m + OVER_n + QUAR_o + BIMO_z + u_p + e_{ijklmnop}$$

where y_{ijklp} and $y_{ijklmnop}$ = the measurements for milk yield and flow traits at udder and quarter levels, respectively, for models [1] and [2]; μ = overall mean; PAR_i = the fixed effects of parity ($i = 1, \geq 2$ lactations); $STAGE_j$ = fixed effect of stage of lactation ($j = 0$ to 100, 101 to 200, >200 d); $PEAK_k$ = fixed effect of peak flow rate score ($k = 1$ to 3); SCC_l = fixed effect of somatic cell count score ($l = 1$ to 3); DEC_m = fixed effect of the duration of decline phase ($m = 1$ to 3); $OVER_n$ = fixed effect of the duration of overmilking phase ($n = 1$ to 3); $QUAR_m$ = fixed effect of quarter positions ($m = 1$ to 4); $BIMO_z$ = the fixed effects of bimodality ($z = 1, 2$); u_p = random effect of cow, $u_p \sim N(0, \sigma_c^2)$; and $e_{ijklmnop}$ = random error, assuming $e_{ijklmnop} \sim N(0, I \sigma_e^2)$.

RESULTS

Somatic cell count was not influenced by parity or PFR. The lowest SCC was found for cows <100 DIM (4.57 ± 0.08 log SCC) and highest for cows >200 DIM (5.08 ± 0.08 log SCC, $P < 0.05$; cows with 100 to 200 DIM were intermediate, 4.79 ± 0.08 log SCC). The lowest SCC was found in front left quarters (4.64 ± 0.08 log SCC) and the highest SCC was found in the rear

right quarters [4.86 ± 0.08 log SCC, $P < 0.05$; right front (4.73 ± 0.08), and left rear (4.78 ± 0.08) were intermediate].

The SCC differentially affected whole udder milk flow and quarter level milk flow (Table 1). At both the udder and quarter levels, milk yield was reduced in groups with high SCC. Quarters with high SCC ($>500 \times 10^3$ cells/mL) had lower PFR and longer overmilking phases compared with quarters with low SCC ($<200 \times 10^3$ cells/mL). There was a tendency for longer duration of the decline phase in quarters with high SCC but this effect was not seen at the udder level.

The effect of bimodality influenced most of the studied parameters (Table 2). The milk flow curves with bimodality had greater peak flow rate and lower milk yield. There was no effect on the decline phase at the udder level and a longer decline in bimodal milk flows at the quarter level. Quarters with bimodality had longer overmilking phases. In groups of cows with low, middle, and high SCC, there were ratios of curves without:with (%) bimodality of 11:15, 23:21, and 12:18, respectively, at the udder level and 4:5, 47:34, and 4:6, respectively at the quarter level.

The duration of the decline phase at the quarter level influenced all measured end points except the duration of the increase phase (Table 3). Quarters with long duration of the decline phase (≥ 80 s) had higher SCC and higher PFR but had lower milk yield compared with quarters with lower duration of the decline phase (<27 s). Quarters with longer duration of decline phase had longer duration of overmilking. Duration of the overmilking phase affected all measured parameters except SCC (Table 3).

DISCUSSION

The effect of parity, the stage of lactation, PFR, and teat position on milk flow characteristics are described in more detail elsewhere (Tančin et al., 2006a). We included these factors in the statistical model because

Table 2. Least squares means ($\pm$ SEM) of measured variables at udder and quarter levels in relation to bimodality (no or yes)

Variable	Udder level bimodality		<i>P</i> <	Quarter level bimodality		<i>P</i> <
	No	Yes		No	Yes	
Number	375	429		1,823	1,439	
Milk yield, kg	18.61 $\pm$ 0.43	17.19 $\pm$ 0.43	0.0001	4.08 $\pm$ 0.14	3.83 $\pm$ 0.14	0.0001
Milking time, s	458 $\pm$ 13	428 $\pm$ 14	0.0001	375 $\pm$ 12	358 $\pm$ 12	0.0001
Peak flow, kg/min	3.76 $\pm$ 0.08	3.91 $\pm$ 0.08	0.0001	0.86 $\pm$ 0.04	0.93 $\pm$ 0.05	0.0001
Milk yield in 1st min, g	1,791 $\pm$ 93	1,563 $\pm$ 92	0.0001	411 $\pm$ 22	356 $\pm$ 23	0.0001
Phase increase, s	76 $\pm$ 2	90 $\pm$ 2	0.0001	69 $\pm$ 3	83 $\pm$ 4	0.0001
Phase plateau, s	208 $\pm$ 9	170 $\pm$ 9	0.0001	241 $\pm$ 15	208 $\pm$ 16	0.0001
Phase of decline, s	173 $\pm$ 10	166 $\pm$ 10	0.2266	60 $\pm$ 5	73 $\pm$ 4	0.0001
Phase of overmilking, s				61 $\pm$ 7	79 $\pm$ 7	0.0001
SCC log 10, cells/mL				4.78 $\pm$ 0.07	4.85 $\pm$ 0.07	0.2091

of their effects on milk flow characteristics. The results were similar to those published in Tančin et al. (2006a) and are not shown.

Later-lactation cows had greater SCC, in agreement with observations made by others (Miller and Paape, 1988; Laevens et al., 1997). Multiparous cows had numerically higher SCC as compared with primiparous cows and this difference is in agreement with other findings (Laevens et al., 1997). Rear quarters have higher SCC than fore quarters (Tančin et al., 2002), which was confirmed in the present work.

One of the most important steps in the prevention of mastitis is a well-prepared cow for milking (Rittershaus et al., 2001). Because of short udder preparation there was a high number of bimodal curves of milk flow at both the udder and quarter levels in present study. Short udder preparation indicates that clusters were attached to the udder before milk ejection was complete (Bruckmaier and Blum, 1998; Tančin and Bruckmaier, 2001). In the present study, the bimodal curves at both udder and quarter levels had higher PFR. Cows with higher PFR, therefore, are more sensitive to short udder preparation. Quarters with bimodal curves had a longer duration of increase, a longer decline, and a longer over-

milking phase. Similar effects were observed by Wellnitz et al. (1999).

The duration of the decline phase and the PFR could be important factors related to SCC. We found higher SCC in quarters with a decline phase duration of ≥ 80 s. The data agree with our published results (Tančin et al., 2002). The quarters with a longer decline phase had less milk yield and higher PFR than quarters with a shorter decline phase. Quarters with a longer overmilking phase had lower milk yield and higher PFR, but there was no effect on SCC. On the basis of these findings we suggest that quarters with a long overmilking phase are quarters that are milked out faster because of a higher PFR and a lower milk yield. Quarters with a long decline phase could be more sensitive to health problems because they tend to be the quarters with high PFR (Grindal and Hillerton, 1991).

When SCC was evaluated, no difference in PFR at the udder level was detected but a reduction of PFR in quarters with high SCC was observed. These quarters had the longest duration of the decline phase in spite of the lowest PFR. We believe that the presence of one or more quarters with high SCC within such udders reduces milk yield and consequently PFR. Additionally,

Table 3. Least squares means ($\pm$ SEM) of measured variables in relation to the duration of decline and overmilking phases

Variable	Category of decline, s			<i>P</i> <	Category of overmilking, s			<i>P</i> <
	<27	27 to 79	≥ 80		<15	15 to 99	≥ 100	
Number of quarters	789	1,695	778		985	1,258	1,019	
Milk yield, kg	4.04 $\pm$ 0.15 ^a	4.11 $\pm$ 0.14 ^a	3.75 $\pm$ 0.15 ^b	0.0001	4.27 $\pm$ 0.15 ^a	3.98 $\pm$ 0.14 ^b	3.65 $\pm$ 0.15 ^c	0.0001
Milking time, s	385 $\pm$ 13 ^a	359 $\pm$ 13 ^b	358 $\pm$ 13 ^b	0.0001	427 $\pm$ 12 ^a	366 $\pm$ 12 ^b	309 $\pm$ 13 ^c	0.0001
Peak flow, kg/min	0.79 $\pm$ 0.05 ^a	0.89 $\pm$ 0.05 ^b	0.99 $\pm$ 0.05 ^c	0.0001	0.83 $\pm$ 0.05 ^a	0.90 $\pm$ 0.04 ^b	0.96 $\pm$ 0.04 ^c	0.0001
Milk yield in 1st min, g	346 $\pm$ 22 ^a	392 $\pm$ 23 ^b	400 $\pm$ 23 ^c	0.0001	334 $\pm$ 23 ^a	380 $\pm$ 21 ^b	426 $\pm$ 23 ^c	0.0001
Phase increase, s	75 $\pm$ 4	75 $\pm$ 4	76 $\pm$ 4	0.7471	80 $\pm$ 5 ^a	75 $\pm$ 4 ^b	72 $\pm$ 4 ^b	0.0002
Phase plateau, s	286 $\pm$ 16 ^a	232 $\pm$ 15 ^b	161 $\pm$ 15 ^c	0.0001	278 $\pm$ 15 ^a	227 $\pm$ 14 ^b	173 $\pm$ 15 ^c	0.0001
Phase of decline, s					75 $\pm$ 4 ^a	68 $\pm$ 4 ^b	65 $\pm$ 5 ^b	0.0001
Phase of overmilking, s	63 $\pm$ 7 ^a	74 $\pm$ 7 ^b	71 $\pm$ 7 ^b	0.0025				
SCC log 10, cells/mL	4.68 $\pm$ 0.08 ^a	4.87 $\pm$ 0.07 ^b	4.91 $\pm$ 0.08 ^b	0.0003	4.80 $\pm$ 0.08	4.77 $\pm$ 0.08	4.85 $\pm$ 0.08	0.1526

^{a-c}Least squares means within a row of evaluated level without a common superscript letter were significantly different at *P* < 0.05.

we can speculate that reduced PFR in such quarters could be related to high SCC by influencing the free flow of milk through milk ducts from alveoli to cistern. Other unknown peripheral mechanisms may limit milk flow as well (Bruckmaier et al., 1993). The relationship between SCC and the decline phase is more difficult to explain because we do not know if a high SCC is a consequence of or the reason for the longer duration of the decline phase. The majority of machine-induced infections occur near the end of milking and a possible explanation could be adapted from Philpot and Nickerson (1991). They discussed the possible importance of reduced milk flow near the end of milking. Reduced milk flow near the end of milking decreases the chance of microorganisms being flushed out of the teat and increases the likelihood of infection in the quarter. The duration of decline phase at the quarter level, therefore, should be minimized because of the possible negative relationship to udder health. Present machine milking systems, however, are not able to reduce the duration of the decline phase. A reduction of vacuum (Ipema et al., 2005) especially for quarters with high PFR and (or) better cow preparation for milking (reduction of bimodality) could be important factors to reduce the duration of the decline phase.

The duration of the decline phase at the udder level indicates the overmilking of one or more quarters. No effect of SCC score on the decline phase at the udder level was observed although quarters with high SCC had the longest overmilking. A negative effect of the duration of overmilking phase on udder health at the udder level has been described (Natzke et al., 1978; Naumann et al., 1998) but this relationship seems to have less importance at the quarter level (Wellnitz et al., 1999). Our data also showed that quarters with long overmilking phases did not differ in SCC from quarters with short overmilking phases. Osteras and Lund (1988) reported that overmilking for >1 min predisposes cows to subclinical mastitis under field conditions.

CONCLUSIONS

We described relationships between milk flow variables at both the udder and quarter levels and SCC in the same cows throughout lactation. The duration of the decline phase in connection with PFR could be an important factor related to SCC. The quarters with high SCC had lower PFR and milk production, and higher overmilking phases. However, the duration of overmilking did not influence the SCC. Reduction in the duration of decline and overmilking phases seem to be important for good milking practice. This finding could be considered as a potential critical point in mastitis incidence

especially in relation to setting default parameters in milking machines and milking routine.

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