Factors Affecting Milk Flow Traits in Dairy Cows: Results of a Field Study

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ABSTRACT

The study of milk flow curves provides useful information for enhancing milking efficiency and protecting udder health by adapting milking machine and milking procedures to the physiological requirements of the cow. The aim of this experiment was to investigate, using field data, the relationships among traits of the milk flow curves, their sources of variation, and milking performances in terms of milk production, machine-on time, and udder health. A total of 2,486 milk flow curves of the whole udder were collected in 82 Italian Holstein-Friesian dairy herds in the Lombardy region of Italy. Approximately one-third (35.1%) of milk flow curves were classified as bimodal. Most flow characteristics were influenced by lactation number, days in milk, and peak flow but also strongly affected by premilking operations. Proper udder preparation, including forestripping and predipping, resulted in better milking performances compared with poor preparation, with greater milk yield per milking, shorter milking time, and lesser bimodality. Premilking delay time, between the start of teat stimulation and cup attachment, affected milking time significantly: The shortest milking time was obtained for a range of delay time between 1 and 60 s. As the delay time increased, the percentage of bimodality dropped significantly. Increasing the number of clusters per operator led to greater percentages of bimodal curves. The greater somatic cell count of cows with bimodal curves supports the hypothesis of the negative effect of bimodality on udder health and indicates the importance of avoiding its occurrence using proper premilking procedures.

Key words: dairy cow, milk flow, milking procedure

INTRODUCTION

The shape of milk flow curve in dairy cows during milking is mainly affected by genetic traits and milking conditions (i.e., machine characteristics, milking rou-

tine, and milking interval; Tancin et al., 2006). Study of milk flow during milking provides useful information for enhancing the efficiency of milking process and protecting udder health. Milk is stored in 2 compartments of the mammary gland: the cistern and the alveolar tissue. Contribution of alveolar milk to total milk in the udder decreases with milking interval (after a 12-h interval the alveolar fraction is approximately 80% of total milk) and depends on lactation number and stage of lactation (Pfeilsticker et al., 1996; Ayadi et al., 2004). The cisternal milk fraction is ready for removal by surmounting the barrier of teat sphincter; in contrast, the alveolar milk has to be shifted actively into the cisternal cavities via the milk ejection reflex. Tactile teat stimulation (e.g., cleaning, forestripping) activates a neuroendocrine mechanism resulting in oxytocin release that causes contraction of myoepithelial cells surrounding the alveoli and ejection of alveolar milk (Bruckmaier and Blum, 1996). Lag time from the start of stimulation until the onset of milk ejection is 1 to 2 min depending on the degree of udder filling (Bruckmaier and Hilger, 2001). A proper prestimulation is essential to obtain continuous and rapid milk removal. In contrast, without prestimulation, the milk ejection reflex is delayed, because it is only induced by the attachment of teat cups, and a transiently reduced milk flow generally occurs after the removal of cisternal milk before alveolar milk ejection. This phenomenon is revealed by bimodal milk flow curves (Bruckmaier and Blum, 1996; Dodenhoff et al., 1999a). Bimodality can have negative effects on milking efficiency causing an extension of machine-on time (Bruckmaier and Blum, 1996) and it is thought to affect teat and udder health negatively because of its similarity to overmilking (Bruckmaier et al., 1995). Dodenhoff et al. (1999a) reported a significant relationship between bimodality and milk SCC in Holstein cows. As a consequence, to ensure immediate and continuous milk flow after the start of milking and total milk removal, an udder prestimulation of 20 to 90 s, depending on the degree of udder filling (Weiss and Bruckmaier, 2005), is recommended. Rasmussen et al. (1992) suggested an optimal prestimulation of 20 to 30 s associated with a delay of 1.3 min from the beginning of preparation to machine

Received April 10, 2006.

Accepted November 14, 2006.

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attachment. Longer delays generally result in reduced machine-on time and in enhanced peak or average flow rate (Bruckmaier et al., 1995; Hogeveen and Ouweltjes, 2003; Weiss and Bruckmaier, 2005). Rasmussen et al. (1992) also reported increased milk yield for Danish Jersey cows in response to longer udder preparation. On the other hand, an excessive delay between the activation of the milk ejection reflex and milk evacuation from the udder can negatively affect milk removal resulting from milk reflux to the ductal and alveolar compartments (Caja et al., 2004). As labor costs have increased and farms have become larger, the amount of time spent stimulating teats has decreased, consequently reducing the time applied for udder cleaning and preparation (Hogeveen and Ouweltjes, 2003).

In addition to bimodality, many other characteristics of the milk flow curves can be useful in revealing reduced milking performances or situations that can be hazardous to udder health. Large quarter peak flows are associated with great susceptibility to bacterial infection because bacteria can enter the udder more easily through larger or slacker teat sphincters (Grindal and Hillerton, 1991). Extended machine-on time may increase the incidence or severity of teat-end callosity (Neijenhuis et al., 2000) and this lesion influences clinical mastitis (Neijenhuis et al., 2001). Long duration of the decline phase of the milk flow curve seems to have positive correlation with SCC, either for the single quarter or for the whole udder (Dodenhoff et al., 1999b; Tancin et al., 2002). Overmilking causes unnecessary increase in machine-on time and leads to edema and bad teat conditions (Hamann, 1990; Hillerton et al., 2002).

The aim of this research was to investigate, on the basis of on-farm milking data, the relationships among the traits of milk flow curves, their main sources of variation, and milking performance in terms of milk production, machine-on time, and udder health, evaluated as SCC.

MATERIALS AND METHODS

Data Collection

The study was conducted on 82 Italian Holstein-Friesian dairy herds in Lombardy, Italy, in 2004. Each farm was visited once during milking operation. A total of 2,486 milk flow curves of the whole udder obtained from different cows were collected with a continuous electronic milk flow meter (Lactocorder, WMB, Balgach, Switzerland). The Lactocorder measured milk flow, milk yield, and electrical conductivity throughout the milking. Milk flow characteristics were detected every 0.7 s and saved at intervals of 2.8 s (WMB, 2005). The flow profile was divided into 5 phases: 1) incline

phase (from milk flow rate >0.5 kg/min until the start of the plateau phase); 2) plateau phase (phase of steady flow is determined by the slopes of the milk flow profile as described in WMB, 2005); 3) decline phase (from end of the plateau phase until milk flow dropped below 0.2 kg/min); 4) overmilking phase (period from milk flow rate <0.2 kg/min until cluster removal); and 5) stripping phase (period at the end of milking, with milk flow rate >0.2 kg/min for at least 4.2 s). Peak milk flow was defined as the maximum milk flow during any 22.4-s period and the average milk flow was calculated from duration of main milking (the sum of increase, plateau, and decline phases) and milk yield. Total milking time (or machine-on time) was calculated as the sum of all the phases (incline, plateau, decline, overmilking, and stripping phases) from attachment until cluster removal. Peak milk conductivity was defined as the maximum electrical signal obtained between the beginning of milk flow and the plateau phase. Bimodality of milk flow was detected if a curve had a flow pattern with 2 increments separated by a clear drop in milk flow for more than 200 g/min within 1 min after the start of milking (Dzidic et al., 2004).

Individual SCC were obtained from the database of AIA (Italian Breeders Association) and corresponded to the results of the test day nearest to the date of the milk flow monitoring (maximum 15 d before or after this date). The SCC values (excluded zero values) were converted to linear scores (**LS**) by following equation: $LS = \log_2 (SCC/100) + 3$ (Wiggans and Shook, 1987). A form was developed to gather information on milking procedures (teat cleaning, forestripping, predipping, cup attachment delay time, and postdipping), milking parlor characteristics (type, size, number of operators), and milking machine settings (machine stripping, automatic cluster removal). The form was completed by a trained operator during milking time.

Statistical Analyses

All the data were analyzed by ANOVA by using a GLM procedure (SAS Inst. Inc., Cary, NC). The model was:

$$y_{ijkl} = \mu + LN_i + S_j + LNS_{ij} + C_k \text{ (or } D_k \text{ or } E_k \text{ or } F_k) + e_{ijkl},$$

where y_{ijkl} = dependent variable; μ = overall mean; LN_i = effect of lactation number ($i = 1$ to 2; primiparous and multiparous); S_j = effect of stage of lactation ($j = 1$ to 2; <150 or >150 DIM); LNS_{ij} = effect of lactation number $\times$ stage of lactation interaction; C_k = effect of peak milk flow rate classes ($k = 1$ to 3; or D_k = effect of different premilking operations, $k = 1$ to 4; or E_k = effect of

different attachment delay time classes, $k = 1$ to 3; or F_k = effect of type of milking parlor and number of clusters, $k = 1$ to 6), and e_{ijkl} = residual error. Orthogonal contrasts were constructed to evaluate differences among least-squares means.

Pearson correlation analysis was performed by using the CORR procedure (SAS Institute). Relationships among average values of milk yield, lactation number, DIM, peak milk flow rate, time of incline phase, bimodality, peak milk conductivity, LS, teat cleaning, predipping, forestripping, attachment delay time, and number of clusters per operator were evaluated for the 82 farms by a multiple correspondence analysis (CORRESP procedure; SAS Institute) to find a low-dimensional graphical representation of the rows and columns of a contingency table.

RESULTS AND DISCUSSION

Milk Flow Traits

The 82 commercial dairy farms involved in the study had, on average, 146 ± 101 lactating cows. On each farm, the percentage of monitored cows as a proportion of total lactating cows was $32 \pm 20\%$. Milking parlors were utilized on all farms and the most common type was a herringbone parlor (56.1% of total farms). Average number of milking clusters in the parlor was 17.5 ± 9.7 . Average number of milking operators was 1.5 ± 0.6 . Number of cows per milker was 101 ± 59 and number of clusters per milker was 12.1 ± 6.3 . Average lactation number of monitored cows was 2.2 ± 1.4 and average DIM was 243 ± 139 . Daily milk yield was, on average, 28.8 ± 8.8 kg/d and mean LS was 3.15 ± 1.58 .

On average, milk yield per milking was 13.9 ± 4.6 kg and peak milk flow rate was 3.8 ± 1.2 kg/min. Total milking time was, on average, 6.9 ± 2.4 min, similar to the value of machine-on time reported by Bruckmaier et al. (1995) for Holstein-Friesian cows. More than one-third of milkings (36%) exceeded 7 min (Figure 1), which might have detrimental effects on teat conditions as reported by Neijenhuis et al. (2000). Prolongation of machine-on time was partially explained by extended overmilking and stripping phases as shown by the correlation values between the duration of these phases and total milking time ($r = 0.39$ and $r = 0.45$ for overmilking and stripping phases, respectively). The incline phase was very short (0.89 ± 0.47 min), but showed wide variability (Figure 1). In our research, a large percentage of milk flow curves were classified as bimodal (35.1%) in accordance with previous findings (Sandrucci et al., 2005). In a study performed on 13,969 Bavarian Holstein cows, Dodenhoff et al. (1999a) reported percentages of bimodality from 21 to 24%, depending on lactation number. The plateau phase had

an average duration of 2.3 ± 1.7 min and the decline phase had a very long duration (2.7 ± 1.4 min). Most milking equipment in the monitored herds utilized automatic takeoffs (96.2%). Despite having automatic takeoffs, time of overmilking phase was rather long (0.8 ± 1.1 min), corresponding to 12.8% of milking time (Figure 1). Overmilking causes an unnecessary increase in machine-on time, leading to poor teat conditions (Hamann, 1990; Hillerton et al., 2002). Machine stripping at the end of milking was carried out by 28% of farms in which time of the machine stripping phase was 1.1 ± 0.9 min (corresponding to 15.9% of total milking time). Stripping milk yield, however, was only 0.6 ± 0.7 kg (4.5% of total milk yield).

Correlation and Correspondence Analyses

Pearson correlation coefficients indicated that milk yield per milking was positively related to peak milk flow rate ($r = 0.33$; $P < 0.001$), total milking time ($r = 0.47$; $P < 0.001$), and time of the plateau phase ($r = 0.43$; $P < 0.001$). Time of incline phase revealed a positive correlation with bimodality of the milk flow curves ($r = 0.58$; $P < 0.001$) as a consequence of the longer time required to reach the plateau phase when a transient reduction of milk flow occurred. As expected, LS was inversely related to milk yield per milking ($r = -0.20$; $P < 0.001$), because of reduced milk production of mastitic udders (Brown et al., 1986) and the effect of dilution (Dodenhoff et al., 1999a). The LS showed a positive correlation with peak milk conductivity ($r = 0.25$; $P < 0.001$). In fact, electrical conductivity tends to increase in milk from infected quarters because of increased concentrations of Na^+ and Cl^- due to damage to the mammary epithelium and altered permeability of the blood-milk barrier (Bansal et al., 2005; Norberg, 2005). In the present study, duration of the decline phase did not correlate with peak flow rate and LS, which is in contrast with other reports (Dodenhoff et al., 1999b; Tancin et al., 2002).

A multiple correspondence analysis evaluated the relationships among average farm values (82 observations) converted in categories for a contingency table. Only the following categories were significant in the correspondence analysis: milk yield, peak milk flow rate, duration of incline phase, percentage of bimodality, LS, peak milk conductivity, and number of clusters per milker. The first dimension described 31% of the total variation (Figure 2) and the second dimension described 25%. Results of the analysis showed that the number of clusters per milker, bimodality, duration of incline phase, and peak milk conductivity had a strong effect on inertia in the first dimension, where inertia refers to the variability of the coordinates in each di-

Figure 1. Frequency of incline phase time (white bars), overmilk phase time (gray bars), and total milking time (black bars).

mension. Milk yield and peak flow rate influenced inertia in the second dimension. The farms with bimodality <33%, small number of clusters per milker, peak milk conductivity <6.4 mS/cm, and duration of incline phase

<0.9 min were clustered in the same space and showed a positive correlation. In contrast, they had a negative correlation with the farms having a bimodality >33%, large number of clusters per milker, peak milk conduc-

Figure 2. Multiple correspondence coordinates in 2 dimension axes for milk flow traits, milk yield, milk electrical conductivity, linear score [LS = $\log_2$ (SCC/100) + 3; Wiggins and Shook, 1987], and number of clusters per operator for 82 farms.

Table 1. Least squares means for lactational performance and milk flow traits by lactation number and stage of lactation in Italian Holstein-Friesian cows

Item	Lactation no.		Lactation no. ¹	Stage (DIM)		SE	Stage ²	Lactation no. × stage ³
	1 (n = 1,017)	>1 (n = 1,469)		<150 (n = 990)	>150 (n = 1,496)			
Milk yield, kg/milking	13.5	14.9	<0.001	16.0	12.4	0.13	<0.001	<0.001
Average milk flow rate, kg/min	2.38	2.47	0.003	2.48	2.36	0.023	<0.001	<0.001
Peak milk flow rate, kg/min	3.53	3.92	<0.001	3.70	3.75	0.038	0.351	<0.001
Total milking time, min	6.78	7.17	<0.001	7.63	6.31	0.074	<0.001	0.841
Duration of incline phase, min	0.86	0.90	0.039	0.86	0.90	0.015	0.023	0.234
Duration of plateau phase, min	2.61	2.24	<0.001	2.99	1.86	0.050	<0.001	0.600
Duration of decline phase, min	2.44	2.97	<0.001	2.83	2.58	0.043	<0.001	0.564
Bimodality, ⁴ %	34.7	33.1	0.427	27.3	40.6	1.52	<0.001	0.909
Peak conductivity of milk, mS/cm	6.25	6.60	<0.001	6.33	6.52	0.022	<0.001	0.003
Linear score ⁵	3.02	3.47	<0.001	2.94	3.55	0.065	<0.001	<0.001

¹Effect of lactation number.²Effect of stage of lactation.³Interaction between lactation number and stage of lactation effects.⁴Bimodality: presence in the milk flow curve of 2 increments separated by a drop in milk flow for more than 200 g/min within 1 min after the start of milking (Dzidic et al., 2004).⁵Linear score: $\log_2(\text{SCC}/100) + 3$; Wiggans and Shook (1987).

tivity >6.4 mS/cm, and duration of incline phase >0.9 min.

Lactation Number and Stage of Lactation

Most milk flow characteristics were influenced by lactation number and DIM (Table 1), partly because of different milk yields. Multiparous cows showed greater milk production per milking and longer total milking time than primiparous cows. Peak milk flow rate was 3.53 vs. 3.92 kg/min ($P < 0.001$) for primiparous and multiparous cows, respectively. Similar effects of lactation number on milk flow were reported for Holstein cows by Dodenhoff et al. (1999a). Because of increasing peak milk flow rate, duration of the plateau phase decreased with increasing lactation number (2.61 vs. 2.24 min, $P < 0.001$) and duration of the decline phase increased (2.44 vs. 2.97 min, $P < 0.001$). Decrease of duration of the plateau phase from primiparous to multiparous cows agrees with findings of other authors (Bagnato et al., 2003). Tancin et al. (2006) observed a significant increase in the duration of the decline phase at the whole udder level from primiparous to multiparous cows. In the present study, peak milk conductivity and LS increased ($P < 0.001$) along with increasing lactation number. These increases are consistent with the increased peak milk flow rate for older cows and with results of another study (Norberg, 2005).

As expected, average milk production per milking decreased ($P < 0.001$) as DIM increased. From <150 DIM to >150 DIM, a reduction ($P < 0.001$) of total milking time and average milk flow rate was detected, confirming results reported by Bruckmaier et al. (1995). Percentage

of bimodal curves increased ($P < 0.001$) throughout lactation (<150 DIM = 27.3% and >150 DIM = 40.6%). This bimodality was partly the result of delayed ejection of the alveolar milk fraction consequent to reduction of udder filling throughout lactation (Bruckmaier and Hilger, 2001; Weiss and Bruckmaier, 2005). Progressive decrease of cisternal milk (Pfeilsticker et al., 1996; Caja et al., 2004) may also be responsible for the increasing percentage of bimodality during lactation. This phenomenon indicates the need for prolonged stimulation in late-lactation cows to obtain continuous milk flow during milking. Both peak milk conductivity and LS increased ($P < 0.001$) between stages of lactation (<150 vs. >150 DIM). An increase in electrical conductivity of milk during lactation was also reported by Norberg et al. (2004). The shape of the conductivity curve resembled the lactation curve for SCC. From our data, the interaction between lactation number and stage of lactation effects was significant ($P < 0.001$) for peak milk flow rate. Bagnato et al. (2003) showed that first-lactation cows increased their ability to release more milk per unit of time at milking as lactation progressed, but older cows had decreased peak milk flow rates as lactation progressed because of reduced milk production and less persistency.

Peak Milk Flow Rate

All individual milk flow curves were grouped based on peak milk flow rate: from the first (<3 kg/min) to the last class (>4 kg/min) of peak milk flow rate (Table 2). There was a significant ($P < 0.01$) difference in milk production per milking as reported previously by Wagner and Ruegg (2002). In addition, duration of the

Table 2. Least squares means for lactational performance and milk flow traits by peak milk flow rates in Italian Holstein-Friesian cows

Item	Peak milk flow rate, kg/min			SE
	<3 (n = 643)	3 to 4 (n = 899)	>4 (n = 944)	
Milk yield, kg/milking	12.5 ^c	14.6 ^b	15.4 ^a	0.17
Average milk flow rate, kg/min	1.64 ^c	2.34 ^b	3.03 ^a	0.020
Total milking time, min	8.47 ^a	7.15 ^b	5.98 ^c	0.090
Duration of incline phase, min	0.77 ^c	0.88 ^b	0.96 ^a	0.021
Duration of plateau phase, min	3.70 ^a	2.42 ^b	1.46 ^c	0.057
Duration of decline phase, min	3.03 ^a	2.84 ^b	2.59 ^c	0.057
Bimodality, ¹ %	25.0 ^c	30.6 ^b	42.0 ^a	2.04
Peak conductivity of milk, mS/cm	6.40 ^b	6.46 ^b	6.56 ^a	0.030
Linear score ²	3.12 ^b	3.20 ^b	3.53 ^a	0.089

^{a-c}Means within a row with different superscripts differ ($P < 0.01$).

¹Bimodality: presence in the milk flow curve of 2 increments separated by a drop in milk flow for more than 200 g/min within 1 min after the start of milking (Dzidic et al., 2004).

²Linear score: $\log_2(\text{SCC}/100) + 3$; Wiggans and Shook (1987).

incline phase and percentage of bimodal curves tended ($P = 0.01$) to increase with increasing peak milk flow rate. These increases probably resulted from the fast emptying of the udder cistern before alveolar milk ejection. These findings confirm the results of Dodenhoff et al. (1999a), who reported greater peak milk flow rate in cows with bimodal curves. The latter authors concluded that an inadequate stimulus is more likely to occur in cows with a greater peak milk flow rate in which milk from the cistern is removed quickly.

As peak milk flow increased, total milking time and duration of plateau phase decreased ($P < 0.01$) in agreement with a recent investigation (Tancin et al., 2006). Peak milk conductivity and LS increased ($P < 0.01$) from the second (3 to 4 kg/min) to the third class (>4 kg/min) of peak milk flow rate (Table 2). Associations among large values of LS, flow rate, and bimodality have been reported (Sandrucci et al., 2005). Grindal and Hilterton (1991) suggested that cows with greater quarter peak milk flows are more susceptible to mastitis. In addition, Bagnato et al. (2003) reported that cows with lesser peak milk flow rate had greater milk production and lesser SCC content.

Premilking Operations

To study the effect of udder preparation, data were divided into 4 groups according to premilking procedures from no udder preparation to applying a complete udder preparation (teat cleaning, forestripping and teat predipping) before cup attachment (Table 3). As expected, better udder preparation resulted in better milking performances compared with poorer preparation: greater milk yield per milking, greater peak milk flow rate, shorter total milking time, shorter time of incline phase, and lesser bimodality. Similar trends of bimodality and ma-

chine-on time for type and duration of premilking preparation were reported by Hogeveen and Ouweltjes (2003). As Bruckmaier et al. (1995) pointed out, the advantage in terms of total milking time of the groups with better preparation is partially compensated by the longer time needed for premilking procedures. Our results are in contrast with the findings of Wagner and Ruegg (2002), who did not observe any effect of forestripping in addition to predipping on milk yield, machine-on time, and flow rate in high- and low-producing cows.

Number and duration of premilking operations were related to the interval between the start of udder preparation and attachment of milking cups to the teats (so-called attachment delay; Rasmussen et al., 1992). To investigate the effect of attachment delay on milk flow traits, all milk flow curves were grouped based on time from the beginning of premilking procedures to attachment: no stimulation, attachment delay <60 s, and attachment delay >60 s (Table 4). Thresholds were chosen in accordance with Bruckmaier et al. (1995), who suggested that a prestimulation time more than 60 s provides good milk letdown. The group without delay corresponded to the group without preparation reported in Table 3, but values were different as a consequence of least squares mean adjustments for unbalanced designs. In agreement with the results of Weiss and Bruckmaier (2005), extended attachment delay did not significantly affect total milk yield. Attachment delay affected milk yield in Danish Jersey cows, but not in Holstein dairy cows (Rasmussen et al., 1992). An increase ($P < 0.05$) was detected in average milk flow rate from the group without delay compared with the other groups as previously documented (Weiss and Bruckmaier, 2005), but peak milk flow rate was unaffected. In our results, a significant effect of attachment delay was observed for total milking time; the shortest ($P < 0.05$) milking time

Table 3. Least squares means for lactational performance and milk flow traits by premilking procedure in Italian Holstein-Friesian cows

Item	None (n = 89)	Cleaning (n = 529)	Cleaning + forestripping (n = 735)	Cleaning + forestripping + predipping (n = 514)	SE
Milk yield, kg/milking	14.2 ^b	13.9 ^b	14.1 ^b	15.4 ^a	0.54
Average milk flow rate, kg/min	2.20 ^c	2.35 ^c	2.48 ^b	2.54 ^a	0.094
Peak milk flow rate, kg/min	3.54 ^c	3.70 ^b	3.87 ^a	3.86 ^a	0.160
Total milking time, min	8.82 ^a	7.14 ^b	6.74 ^c	6.70 ^c	0.299
Duration of incline phase, min	0.98 ^a	0.88 ^{ab}	0.83 ^{bc}	0.82 ^c	0.057
Duration of plateau phase, min	2.67	2.33	2.32	2.45	0.210
Duration of decline phase, min	2.77	2.82	2.67	2.86	0.177
Bimodality, ¹ %	47.3 ^a	32.6 ^{bc}	29.7 ^{cd}	25.4 ^d	6.07
Peak conductivity of milk, mS/cm	6.61	6.46	6.50	6.44	0.090
Linear score ²	3.53	3.02	3.54	3.07	0.273

^{a-d}Means within a row with different superscripts differ ($P < 0.05$).

¹Bimodality: presence in the milk flow curve of 2 increments separated by a drop in milk flow for more than 200 g/min within 1 min after the start of milking (Dzidic et al., 2004).

²Linear score: $\log_2 (\text{SCC}/100) + 3$; Wiggans and Shook (1987).

corresponded to the class with an attachment delay <60 s (Table 4). Prolonged machine-on time occurred during milking when cows were not prestimulated before milking (Bruckmaier and Blum, 1996; Weiss and Bruckmaier, 2005). As expected, duration of the incline phase and percentage of bimodality decreased ($P < 0.05$) with increasing attachment delay.

Table 5 shows the influence of number of clusters per milker in different parlor types on milk flow traits. Each type of parlor had a different optimal number of units per milker depending on working capacity. Increasing the number of clusters per milker may often increase the milking capacity (Hansen, 1999), but can result in a careless milking routine, especially in the udder preparation phase. Based on the distribution of percentage of

bimodality, we used different thresholds to distinguish between proper and improper situations in the different parlor types: 14, 18, and 6 clusters per milker in herringbone, parallel, and side-opening tandem parlors, respectively. Increasing the number of clusters per milker increased the duration of the incline phase ($P < 0.001$) and the percentage of bimodal curves ($P < 0.01$) in all parlor types. Total milking time was longer ($P < 0.001$) only in parallel parlors when the number of clusters per milker increased from <18 to >18.

The classification of the milk flow curves based on the presence or absence of bimodality showed that bimodal curves were associated with less ($P < 0.001$) milk yield per milking (13.8 vs. 14.7 kg/milking), greater ($P < 0.001$) peak milk flow rate (4.1 vs. 3.6 kg/min), longer

Table 4. Least squares means for performance and milk flow traits by attachment delay in Italian Holstein-Friesian cows

Item	Attachment delay ¹			SE
	Without (n = 89)	<60 s (n = 1,527)	>60 s (n = 690)	
Milk yield, kg/milking	13.7	14.0	14.4	0.47
Average milk flow rate, kg/min	2.23 ^b	2.41 ^a	2.45 ^a	0.081
Peak milk flow rate, kg/min	3.58	3.73	3.71	0.136
Total milking time, min	8.50 ^a	6.72 ^c	7.15 ^b	0.256
Duration of incline phase, min	1.07 ^a	0.88 ^b	0.81 ^c	0.054
Duration of plateau phase, min	2.64 ^a	2.36 ^b	2.54 ^a	0.180
Duration of decline phase, min	2.53	2.66	2.72	0.147
Bimodality ² , %	54.5 ^a	35.6 ^b	24.6 ^c	5.34
Peak conductivity of milk, mS/cm	6.48 ^a	6.53 ^a	6.20 ^b	0.079
Linear score ³	3.29 ^{ab}	3.32 ^a	3.03 ^b	0.241

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹Attachment delay: time lasting between the beginning of udder preparation and attachment of milking cups to the teats.

²Bimodality: presence in the milk flow curve of 2 increments separated by a drop in milk flow for more than 200 g/min within 1 min after the start of milking (Dzidic et al., 2004).

³Linear score: $\log_2 (\text{SCC}/100) + 3$; Wiggans and Shook (1987).

Table 5. Least squares means for performance and milk flow traits by parlor type in Italian Holstein-Friesian cows

Item	Herringbone		<i>P</i>	Parallel		<i>P</i>	Side-opening tandem		<i>P</i>	SE
	<14 (n = 933)	>14 (n = 456)		<18 (n = 290)	>18 (n = 302)		<6 (n = 101)	>6 (n = 115)		
Milk yield, kg/milking	14.0	14.6	0.010	13.7	13.4	0.433	11.9	14.8	<0.001	0.43
Average milk flow rate, kg/min	2.43	2.49	0.136	2.47	2.20	<0.001	2.23	2.47	0.022	0.075
Peak milk flow rate, kg/min	3.71	3.88	0.021	3.77	3.46	0.008	3.44	3.72	0.109	0.125
Total milking time, min	6.88	6.86	0.862	6.33	7.29	<0.001	6.35	6.88	0.101	0.232
Duration of incline phase, min	0.84	0.97	<0.001	0.80	1.02	<0.001	0.63	0.94	<0.001	0.049
Duration of plateau phase, min	2.45	2.29	0.076	2.24	2.57	0.027	2.20	2.52	0.153	0.162
Duration of decline phase, min	2.66	2.67	0.905	2.65	2.66	0.933	2.66	2.67	0.944	0.130
Bimodality, ¹ %	29.5	37.5	0.004	27.6	53.7	<0.001	15.9	37.6	0.001	4.87
Peak conductivity of milk, mS/cm	6.38	6.53	<0.001	6.36	6.49	0.047	6.35	6.59	0.013	0.067
Linear score ²	3.24	3.23	0.958	3.10	3.46	0.069	2.85	2.97	0.687	0.210

¹Bimodality: presence in the milk flow curve of 2 increments separated by a drop in milk flow for more than 200 g/min within 1 min after the start of milking (Dzidic et al., 2004).

²Linear score: $\log_2(\text{SCC}/100) + 3$; Wiggins and Shook (1987).

($P < 0.001$) incline phase (1.25 vs. 0.69 min), and shorter ($P < 0.001$) plateau phase (1.7 vs. 2.7 min) compared with normal curves. Peak electrical conductivity of milk (6.7 vs. 6.3 mS/cm) and LS (3.5 vs. 3.2) resulted in greater ($P < 0.001$) bimodality compared with the normal group in accordance with the results of Dodenhoff et al. (1999a).

CONCLUSIONS

The results of our study confirm that, under on-field conditions, milk flow curves of Italian Holstein-Friesian cows tend to show poor profiles: Total milking time and overmilking phase were frequently too long, stripping resulted in a significant waste of time, and the percentage of bimodality was great. Most milk flow traits were significantly affected by lactation number, DIM, and peak milk flow rate, but also by milking procedures, particularly during the premilking phase. Proper udder preparation, including forestripping and predipping, resulted in better milking performances in terms of greater milk yield per milking, greater peak milk flow rate, shorter total milking time, and lesser bimodality compared with poor preparation. Duration of the delay between the beginning of udder preparation and cup attachment affected milking time significantly. The shortest milking time corresponded to an attachment delay time <60 s. Moreover, as attachment delay increased, the percentage of bimodality decreased significantly. Efficiency of the milking process was influenced by parlor size and the number of milkers. Increasing the number of clusters per milker increased the percentage of bimodal milk flow curves probably because of reduced time and quality of premilking procedures. The greater SCC of cows with bimodal curves supports the hypothesis of the detrimental effect of bimodality on udder health and indicates the need to

avoid its occurrence during milking by means of proper premilking procedures.

ACKNOWLEDGMENTS

Gratitude is expressed to Lucio Zanini (SATA specialist) for his contribution to this research. The authors also thank technicians of Associazioni Provinciali Allevatori of Lombardy for their support in data collection.

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