Archiv Tierzucht 54 (2011) 4, 360-373, ISSN 0003-9438

Comparison of the effects of quarter-individual and conventional milking systems on milkability traits

Anika B. Müller, Sandra Rose-Meierhöfer, Christian Ammon and Reiner Brunsch

Department of Engineering for Livestock Management, Leibniz Institute for Agricultural Engineering Potsdam-Bornim (ATB), Potsdam, Germany

Abstract

This study was carried out to investigate a new quarter-individual milking system called MultiLactor® (Siliconform GmbH, Türkheim, Germany). The MultiLactor enables milking on quarter level basis with low vacuum (37 kPa), sequential pulsation and periodic air inlet. Within the same dairy farm, the influence of this quarter-individual milking system (MULTI) on milkability traits was compared with a conventional milking system (CON). CON was equipped with a conventional milking cluster and used alternating pulsation. Vacuum level was adjusted to 40 kPa. For the study, 84 Holstein Friesian cows were randomly selected and uniformly divided into two herds. During the 30-week survey, the milk flow curves were recorded every other week by using a LactoCorder (WMB, Balgach, Switzerland). Significant differences (P<0.05) between both milking systems were found for all milk flow traits, except for milk yield and decline phase. Concerning the incline (tAN) and plateau (tPL) phase, large differences existed between MULTI and CON. The estimated value of tAN calculated for MULTI (29.4 s) took only half of the time when calculated for CON (56.4 s). The estimated value of tPL at CON was reduced by 1.43 min (35 %) compared to MULTI. Milking process at MULTI (8.49 min) took longer time than for CON (7.43 min). From the study, it was concluded that the effect of shorter tAN in the quarter-individual milked cows may be related to additional pre-stimulation by an actuator. In contrast, the longer milking time in MULTI is possibly caused by lower vacuum level and periodic air inlet.

Keywords: quarter-individual milking, conventional milking, milk flow curve, milkability, milking speed

Zusammenfassung

Vergleich von viertelindividueller und konventioneller Melktechnik und deren Einfluss auf verschiedene Melkbarkeitsmerkmale

Die vorliegende Studie wurde durchgeführt, um ein neues viertelindividuelles Melksystem (MultiLactor, Siliconform GmbH, Türkheim, Deutschland) zu untersuchen. Das System verfügt über eine viertelindividuelle Schlauchführung, arbeitet mit Niedrigvakuum (37 kPa), sequenzieller Pulsation und periodischem Lufteinlass. Der Einfluss des viertelindividuellen Melksystems (MULTI) auf verschiedene Melkbarkeitsmerkmale wurde mit einem konventionellen Melksystem (CON) innerhalb eines Betriebes verglichen. CON war mit konventionellen Melkzeugen ausgestattet und nutzte eine Wechseltaktpulsation. Das

Anlagenvakuum betrug 40 kPa. Für die Studie wurden 84 Kühe der Rasse Deutsche Holstein zufällig ausgesucht und gleichmäßig auf zwei Versuchsgruppen aufgeteilt. Die Milchflusskurven wurden über einen Zeitraum von 30 Wochen alle zwei Wochen mit LactoCordern (WMB, Balgach, Schweiz) aufgezeichnet. Mit Ausnahme der Milchmenge und der Dauer der Abstiegsphase, bestanden bei allen anderen Melkbarkeitsmerkmalen signifikante Unterschiede (P<0,05) zwischen beiden Melksystemen. Große Differenzen zwischen MULTI und CON traten hinsichtlich der Dauer der Anstiegs- und Plateauphase auf. Die Anstiegsphase (tAN) im MULTI (29,4 s) war nur halb so lang wie im CON (56,4 s). Andererseits war die Plateauphase (tPL) im CON um 1,43 min (35 %) kürzer als im MULTI. Insgesamt hat der Melkvorgang im MULTI (8,49 min) länger als im CON (7,43 min) gedauert. Die kürzere Anstiegsphase bei den viertelindividuell gemolkenen Kühen könnte auf die zusätzliche mechanische Vorstimulation zurückgeführt werden. Dagegen könnte die längere Gesamtmelkdauer mit dem niedrigeren Melkvakuum und dem periodischen Lufteinlass begründet werden.

Schlüsselwörter: viertelindividuelles Melken, konventionelles Melken, Milchflusskurve, Melkbarkeit, Milchflussgeschwindigkeit

Introduction

Milk yield, udder health and milkability are important factors which have an impact on the dairy industry in developed countries (Petrovski *et al.* 2006, Tančin *et al.* 2006). Machine milking requires gentle, complete and fast removal of milk from the udder under optimal technical and hygienic conditions to maintain animal health (Bruckmaier & Hilger 2001, Lee & Choudhary 2006). During milking, milkability is described by milk flow traits which provide useful information about the efficiency and adequacy of milk release, milking process and milking machine settings (Zucali *et al.* 2009). Among other things, the shape of milk flow curves is affected by milking conditions (Rittershaus *et al.* 2002, Sandrucci *et al.* 2007).

Tančin *et al.* (2006) reported that morning or evening milking significantly influenced all measured milk flow traits because of different milking intervals. All milk flow measures were higher during morning milking except the duration of incline phase (tAN). Parity did not influence tAN just as average (DMG) and peak (HMF) milk flow rates. Furthermore, multiparous cows had significantly higher milk yield than primiparous cows (Tančin *et al.* 2006). In matters of parity and morning or evening milking, Dodenhoff *et al.* (1999) demonstrated the same significant influences on milkability traits as showed by Tančin *et al.* (2006). Furthermore, the statement of Dodenhoff *et al.* (1999) corresponded with Göft *et al.* (1994) that breeding with focus on high DMG did not result in a uniform increase of milk flow, but in an increase of HMF. Zucali *et al.* (2009) also confirmed a close relation between high HMF, short duration of plateau phase (tPL) and high somatic cell count (SCC) in primiparous cows at the beginning of lactation. Naumann *et al.* (1998) showed that cows with very long duration of decline phase (tAB) had the highest SCC caused by over-milking and irritation of individual quarters. Otherwise MIJIĆ *et al.* (2004) demonstrated that cows with a short tAN had the least SCC in milk.

The milking process may be stressful for fresh primiparous cows, due to the novel and close interaction with milker and equipment. In comparison with multiparous cows, the mammary gland is usually characterized by a smaller total milk yield (MGG) (Pfeilsticker *et al.* 1996). They show a lower tPL and higher percentage of bimodal curves (Dodenhoff *et al.* 1999, Sandrucci *et al.* 2007). Bimodal milk flow curves imply a non-continuous milk flow at the beginning of milking.

Naumann & Fahr (2000) demonstrated that at quarter level, tPL was longer in comparison with milk flow curves at udder level. That means that the plateau phase of the complete milking is defined by the udder quarter with the shortest milking time. In contrast to that, the decline phase of the complete milking was considerable longer than decline phase at quarter level. This is a sign of varied milking durations for individual quarters and indicates an unbalanced milk letdown. Hence, it can be concluded that the burden of over-milking concerns mainly the front quarters, which need less time for milking than rear quarters (Naumann & Fahr 2000). In general, milk letdown from each quarter is described with a short incline phase, a long plateau phase and at the end a fast decrease of milk flow (Wellnitz *et al.* 1999, Naumann & Fahr 2000). Milkability traits and breeding goals for an optimal milk release are 3-4.5 kg/min for HMF, 4-5 min for tPL and ≤1 min for tAB (Göft *et al.* 1994). Wessels (2000) noticed that a cow with an average milk flow per minute within main milking phase (DMHG) lower than 2 kg/min and duration of main milking phase (tMHG) above 8 min belongs to the group of slowly milking cows which affect working time negatively.

Kanswohl *et al.* (2007) revealed that an insufficient pre-milking teat preparation under 60 s lead to a decreasing DMG while the duration of whole milking (tMGG) increased. According to Bruckmaier *et al.* (1995), MGG was not influenced by the presence or absence of pre-milking stimulation, whereas DMG and HMF were greater with than without stimulation. Ipema & Hogewerf (2004) investigated the effect of milking machine parameters on DMG in an automatic milking system (AMS) and found out that change of vacuum level or pulsation ratio did not significantly affect MGG per cow. However, raising the vacuum level from 42 to 45 kPa resulted in a 5 % higher DMG.

The MultiLactor, which provides quarter-individual milking, has been developed to reduce unwanted effects of conventional milking systems on the animals. Rose-Meierhöfer *et al.* (2009) could prove that the wrong positioning of teat cups can be avoided if systems with single tube guidance are implemented. The objective of this study was to compare the quarter-individual (MULTI) and the conventional (CON) milking system based on their effects on milkability traits of cows.

Material and methods

Cows and milking procedures

The study was performed from June till December 2009 at a dairy farm located in Thuringia, Germany. Eighty four German Holstein cows were randomly selected and uniformly divided into two experimental herds. This means that cows in all lactations up to the 120th day of lactation at the beginning of the trial were considered. Furthermore, only dairy cows without clinical evidence were used in the trial. Both experimental herds were housed in the same free-stall barn and received the same feed ration. They were milked in different tandem parlours twice a day with a twelve hour milking interval.

All milking procedures were performed by two milking persons. The pre-milking preparations consisted of foremilking and cleaning the udder and teats. Single-use towelettes moisturised with disinfectant were used for cleaning. After that the milking unit was attached. Milking was automatically ended with the detachment of the milking unit. At the end of the milking process each teat was dipped with a solution containing iodine. Teat cups were cleaned and disinfected automatically with water and peracetic acid solution after each cow in both milking parlours. The intermediate cleaning and disinfection were achieved with back flush (CON) and total flush (MULTI) systems.

Milking equipment

During the trial period, CON (Westfalia manufactured by GEA, Bönen, Germany) and MULTI (MultiLactor manufactured by Siliconform GmbH, Türkheim, Germany) were compared. Herd A was milked exclusively with CON (12 milking places) and herd B with MULTI (8 milking places). Both milking parlours had a low level milk line equipped with milk meters.

MULTI consisted of four single milk tubes without a milking claw, which were merged to one long milk tube. Furthermore, the system provided silicon liners and periodic air inlet into the teat cups (BioMilker). The working vacuum level was set to 37 kPa, and sequential pulsation was adopted. This means that pulsation started in each liner individually and successively 25 % out of phase (Rose-Meierhöfer *et al.* 2010). The pulsation rate and ratio were 60 cycles/min and 65:35, respectively. CON was equipped with a conventional milking cluster (Classic Westfalia 300) manufactured by GEA (Bönen, Germany) with a claw volume of 300 ml, silicon liners and a long milk tube. The system working vacuum level was adjusted to 40 kPa. Alternating pulsation with a pulsation rate of 60 cycles/min and a ratio of 60:40 was applied.

Regarding the pre-stimulation, CON used a pulsation rate of 300 pulses at an average vacuum level of 19 kPa lasting for a minute. MULTI applies a special pre-stimulation. Thereby, the cows were induced to milk letdown by application of a mechanical actuator stimulating each teat and the whole udder with oscillating movements of the long milk tubes. The duration of the pre-stimulation was about 50 s and applied a pulsation ratio of 10 % milking phase and 90 % massage phase.

Milk flow measurements

Milk flow measurements were carried out with a continuous electronic mobile milk meter (LactoCorder, WMB, Balgach, Switzerland). The LactoCorder® recorded milk flow throughout the evening milking. The device was vertically attached to every milking place and inserted in the long milk tube in front of the milk meter. The measuring chamber consisted of one transmitting electrode and 60 vertically arranged electrodes. The electrical conductivity was measured at the different levels and an instant milk density profile was provided in intervals of 0.7 s. Finally, an average of four values was stored and saved every 2.8 s. The evaluation was made by special software (LactoPro, WMB, Balgach, Switzerland). The milk flow curve was divided into three main phases:

1. incline phase (from milk flow rate >0.5 kg/min until the start of the plateau phase),
2. plateau phase (time of main milking phase with approximate constant milk flow),
3. decline phase (from the end of the plateau phase until milk flow dropped below 0.2 kg/min).

The main milking phase consists of the three phases described above. Peak milk flow was defined as the maximum milk flow during any period of 22.4 s, in the majority of cases situated within the plateau phase. Average milk flow within main milking phase was calculated from duration of main milking phase divided by milk yield milked within main milking phase.

Milk flow curves of the whole udder were registered every other week for each cow of each experimental herd, over a period of 30 weeks. Having the same number of observations in each week was not possible in each herd due to illness. All selected traits that characterize the milk letdown and milking process are listed in Table 1.

Table 1
Traits that characterize milking process

Abbreviation	Unit	Trait
MGG	kg	Total amount of milk
tMGG	min	Duration of whole milking
tAN	min	Duration of incline phase
tPL	min	Duration of plateau phase
tAB	min	Duration of decline phase
tMHG	min	Duration of main milking phase
HMF	kg/min	Peak milk flow per minute (within 22.4 s)
DMG	kg/min	Average milk flow per minute of whole milking
DMHG	kg/min	Average milk flow per minute within main milking phase

Statistical analysis

The study was based on a data set consisting of 1 053 milk flow curves obtained from 84 different Holstein cows. A mixed linear model was implemented to estimate the influence of several factors and covariables on selected milkability traits. The emphasis in this analysis lay on possible differences between the examined milking systems. In the model milking system (CON, MULTI), lactation (1st, 2nd and ≥3rd lactation) and comparative weeks (n=15) were inserted as fixed effects. Day in milk nested with lactation and milk yield were added as covariables. Furthermore, cows were considered as a random effect. SAS, a statistical software package v 9.1 (SAS 2002), was used for all following analysis concerning different milkability traits. The evaluation of the unbalanced data set was made using the MIXED procedure. Descriptive statistics were calculated with the UNIVARIATE procedure. The following mixed linear model was applied for all traits except MGG:

$$y_{ijkl} = \mu + MS_i + LN_j + CW_k + D(LN_j)x + Mz + K_l + e_{ijkl} \qquad (1)$$

(i=1,2; j=1,2,3; k=1,...,15; l=1,...,84)

where y is the observed value of target variable, μ is the general mean, MS_i is the fixed effect of the i-th milking system, LN_j is the fixed effect of the j-th lactation, CW_k is the fixed effect of the k-th comparative weeks, $D(LN_j)$ is the covariable (day in milk x nested with lactation j), M is the covariable (milk yield z), K_l is the random effect of l-th cow, e_{ijkl} is the residual error.

Global hypotheses for the fixed effects and covariables were tested with F-tests at a significance level of α=0.05. Within effects differences were tested by pair wise t-tests between levels and the results were presented as least square means±standard error. In order to adjust *P*-values to multiple testing, the SIMULATE option was used, keeping a global significance level of α=0.05.

Results

Description of selected milkability traits

Table 2 shows that MGG was 15.3 kg and tMGG was 8 min on average per milking. The investigated cows showed a short tAN (0.7 min). After this, a relative long tPL (3.5 min) and a shorter tAB (2.8 min) followed. Table 2 also presents the statistical values for the same parameters, but calculated for MULTI and CON separately. MGG amounted on average 15.7 kg (MULTI) and 14.9 kg (CON). MULTI needed 32 s to reach tPL; CON required 55 s which was 72 % higher than in MULTI. On average, cows milked with MULTI needed 8.6 min for milk removal, with CON only 7.3 min. The average milk flow per minute within the main milking phase (DMHG) was between 2.1 kg/min (MULTI) and 2.4 kg/min (CON) which corresponded to a difference of 0.3 kg/min.

Table 2
Statistical values of selected traits of milk flow curves for both experimental herds

Milkability traits	TOTAL (n=1 053)		MULTI (n=556)		CON (n=497)	
	µ	SD	µ	SD	µ	SD
MGG, kg	15.31	3.99	15.67	3.64	14.90	4.31
tMGG, min	7.97	2.32	8.56	2.58	7.32	1.80
tAN, min	0.71	0.42	0.53	0.34	0.92	0.40
tPL, min	3.49	2.14	4.22	2.34	2.67	1.52
tAB, min	2.76	1.23	2.88	1.22	2.63	1.23
tMHG, min	6.96	2.28	7.63	2.51	6.21	1.70
HMF, kg/min	3.37	1.06	3.10	0.94	3.68	1.10
DMG, kg/min	2.00	0.55	1.93	0.52	2.09	0.58
DMHG, kg/min	2.27	0.65	2.14	0.58	2.42	0.70

µ: arithmetic mean, SD: standard deviation, TOTAL: both milking systems, CON: conventional milking system, MULTI: MultiLactor

Influencing factors on milkability traits

Regarding the main milking phase, the results (Table 3) stated that the milking system had an influence on tAN and tPL, but not on tAB. Additionally, the milking system did not influence MGG. DMHG was not affected by the number of lactation, but the peak milk flow (HMF). The studied comparative weeks, which took environmental effects into account, influenced all parameters excluding tAB. The results also showed that the covariable milk yield had an influence on all milkability traits, with exception of tAN. Furthermore, it could be noticed that the covariable day in milk nested with lactation, which covered the influence of different stages of lactation, significantly influenced tAB, but not tAN or tPL. The significance of the fixed effects and covariables influence on milk flow traits was tested.

Table 3
Results of F-tests for fixed effects and covariables regarding milk flow traits

Milkability traits	Milking system	Lactation	Comparative week	Milk yield	DIM
MGG, kg	0.8638	<.0001*	<.0001*		<.0001*
tMGG, min	0.0074*	0.0400*	0.0001*	<.0001*	0.0013*
tAN, min	<.0001*	0.5079	0.0015*	0.2864	0.6514
tPL, min	<.0001*	0.0044*	0.0009*	<.0001*	0.1053
tAB, min	0.6038	0.9046	0.0815	<.0001*	0.0368*
tMHG, min	0.0045*	0.0262*	0.0307*	<.0001*	0.0012*
HMF, kg/min	<.0001*	0.0173*	<.0001*	<.0001*	0.1632
DMG, kg/min	0.0066*	0.1694	0.0002*	<.0001*	0.0171
DMHG, kg/min	0.0012*	0.0963	0.0201*	<.0001*	0.0086*

DIM: day in milk nested with lactation, *significant at $\alpha \leq 0.05$ (P>F)

The main focus of attention was on possible significant differences between both milking systems. Therefore, the differences of least square means were analysed for the levels of the fixed effects milking system and lactation.

For all milk flow traits, with the exception of MGG and tAB, significant differences existed between MULTI and CON (Table 4 and 5). MGG and tAB were not affected by the different milking systems. Concerning tAN and tPL, large differences existed between CON and MULTI. Accordingly, estimated value for tAN calculated for MULTI (29.4 s) took only about half as long as calculated for CON (56.4 s). Otherwise tPL at CON was reduced by 1.43 min (35 %) compared to MULTI. All in all the milking process at MULTI took longer than for CON. Looking at the estimated values of tMGG, MULTI milked nearly 69 s longer than CON. Furthermore, cows milked with CON had significantly higher milk flow rates, including HMF (28.3 % higher), DMHG (17.1 % higher) and DMG (12.7 % higher), than cows milked with the quarter-individual milking system.

Table 4
Least square means, standard error and influence of fixed effects upon milk flow traits of main milking phase

Fixed effect	Level	tAN, min		t PL, min		tAB, min		tMHG, min	
		LSM	SE	LSM	SE	LSM	SE	LSM	SE
MS	CON	0.94[a]	0.04	2.71[a]	0.24	2.74[a]	0.14	6.38[a]	0.29
MS	MULTI	0.49[b]	0.04	4.14[b]	0.23	2.85[a]	0.14	7.49[b]	0.29
LN	1	0.65[a]	0.04	4.25[a]	0.36	2.51[a]	0.17	7.40[a]	0.48
LN	2	0.80[b]	0.05	2.77[b]	0.22	2.82[a]	0.16	6.38[a]	0.29
LN	≥3	0.70[ab]	0.05	3.26[ab]	0.32	3.06[a]	0.19	7.02[a]	0.35

LSM: least square means, SE: standard error, MS: milking system, LN: lactation, [a,b,c]Different small letters within fixed effect indicated significant differences at α=0.05 level.

Level of lactation had no influence on the following characteristics: DMG, DMHG, tAB, tMGG and duration of main milking phase (tMHG). On the other hand, tAN and tPL as well as HMF and MGG within the first lactation differed from the second lactation. Only second lactation cows had a significantly higher HMF compared to primiparous cows. Expectedly, MGG rose with the number of lactation. Cows in their second lactation and multiparous cows had significantly higher MGG than primiparous cows. The longest tMGG with nearly 9 min was found for cows in their first lactation.

Table 5
Least square means, standard error and influence of fixed effects upon milk flow traits of milking process

Fixed effect	Level	MGG, kg		tMGG, min		HMF, kg/min		DMG, kg/min	
		LSM	SE	LSM	SE	LSM	SE	LSM	SE
MS	CON	15.45[a]	0.37	7.43[a]	0.29	3.85[a]	0.13	2.13[a]	0.06
MS	MULTI	15.54[a]	0.37	8.49[b]	0.28	3.00[b]	0.13	1.89[b]	0.06
LN	1	13.89[a]	0.42	8.44[a]	0.46	3.04[a]	0.15	1.92[a]	0.07
LN	2	15.98[b]	0.39	7.38[a]	0.28	3.72[b]	0.19	2.13[a]	0.08
LN	≥3	16.62[b]	0.60	8.05[a]	0.34	3.52[ab]	0.17	1.98[a]	0.09

LSM: least square means, SE: standard error, MS: milking system, LN: lactation, [a,b,c]Different small letters within fixed effect indicated significant differences at α=0.05 level.

Milk flow curves

The distribution of different types of milk flow curves ascertained for MULTI and CON was tabulated in Table 6. The classification was realized computationally according to Wessels (2000). Milk flow curves with a gradual (Figure 2) or continuous decrease phase did not differ. Both types added up to about 60 %, representing the main part of all milk flow curves in both milking systems. In the present dataset, the percentages of trapezium shapes (Figure 1), which are considered as ideal for milk release, were only 2.2 % for quarter-individual and 6.4 % for conventional milked cows. Furthermore table 6 shows that the share of curves with bimodality (Figure 1) was higher in the group milked with CON and that MULTI did not have any curves with an air break-in. In regard to milking speed, the shape of curves which describes a slow milk removal (Figure 2) was more than 20 % for MULTI, but only 9 % for CON.

Table 6
Types of milk flow curves and frequency during trial period

Type of milk flow curve	MULTI (n=556)		CON (n=497)	
	n	%	n	%
Gradual or continuous decline phase	380	68.3	295	59.4
Trapezium shape	12	2.2	32	6.4
Bimodality	27	4.9	69	13.9
Air break-in	-	-	14	2.8
Fast milk removal	5	0.9	35	7.0
Slow milk removal	129	23.2	46	9.3
Overmilking	3	0.5	6	1.2

MULTI: MultiLactor, CON: conventional milking system

Discussion

The evaluation of the milking process is necessary to describe the interactions between milking machine, milker and dairy cow. It is also concerned with the efficiency of milking and with the state of udder health (Hamann 1997).

Some authors found differences between morning and evening milking in most observed traits which were normally caused by different milking intervals (Schöne *et al.* 1994).

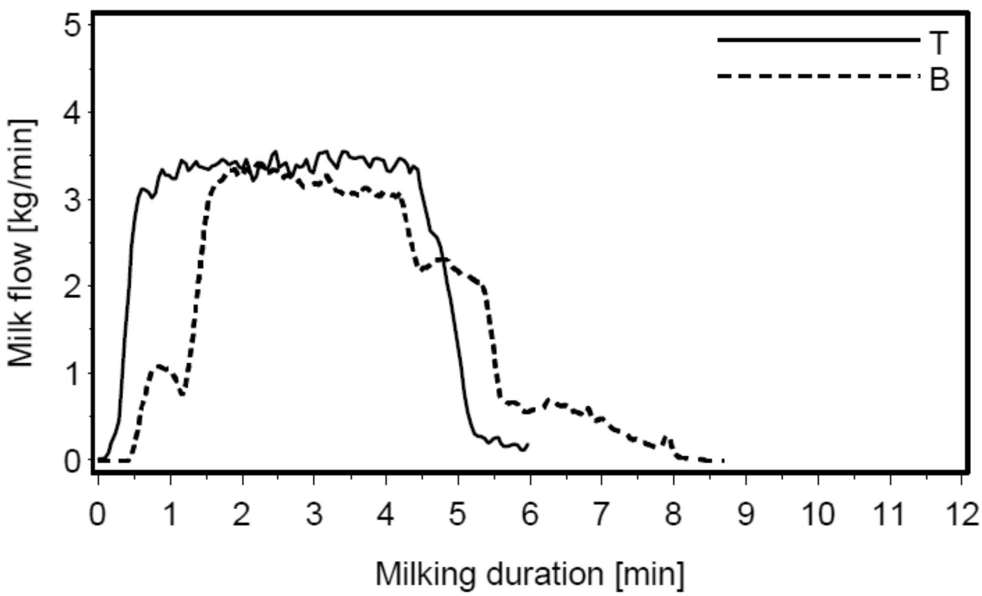

Figure 1
Examples for typical milk flow curves
(T: trapezium shape as optimal milk flow curve, B: unwanted bimodality during incline phase)

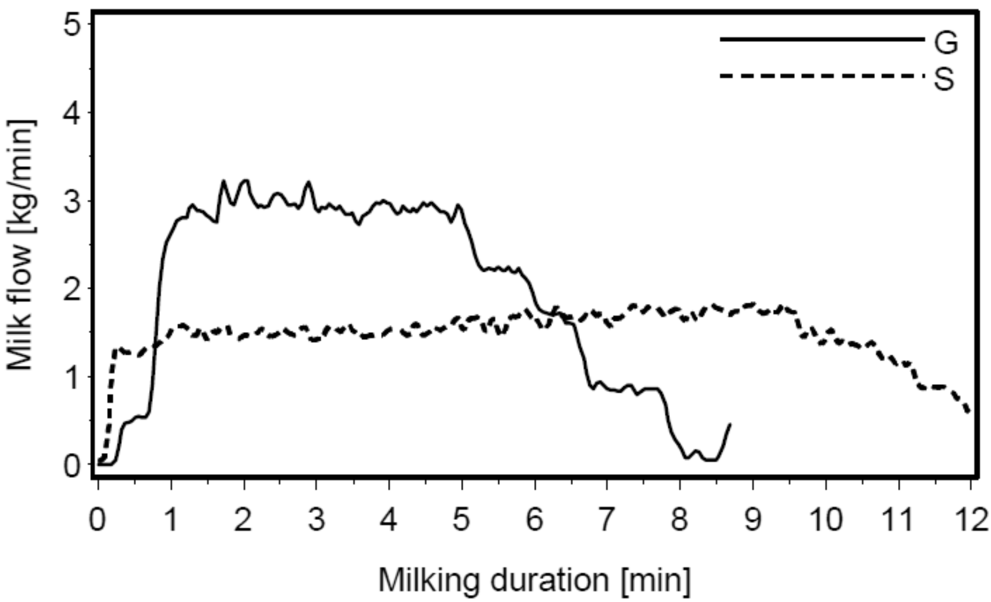

Figure 2
Examples for typical milk flow curves
(G: gradual decline, S: cow with slow milk removal)

Consequently, it is associated with different degrees of udder filling (Tančin *et al.* 2006). In order to improve the validity of the study, only measurements of the evening milking were used.

On closer inspection of the parity effect, Tančin *et al.* (2006) and Strapák *et al.* (2009) discovered that multiparous cows had significantly higher MGG than primiparous cows. Similar to the results of Tančin *et al.* (2006), our results showed a significant difference between primiparous and multiparous cows with reference to MGG, but not with regard to tMGG. Furthermore, Tančin *et al.* (2006) realised that MGG and tMGG slowly, but continuously decreased from the third month of lactation. This fact was also confirmed by the results found in this study; and the results suggest that milk flow characteristics vary because of physiological processes which changed during lactation.

MGG did not differ significantly between MULTI and CON. It can be concluded that MGG did not affect the shape of milk flow curves and the related milkability traits. In contrast, the milking system had a significant effect on tMGG. According to Lee and Choudhary (2006), tMGG might be influenced among other things from animal physiological effects, management practices and vacuum pressure. Ipema and Hogewerf (2008) determined that the vacuum level did not affect MGG, but tMGG decreased significantly when the vacuum was raised from 42 to 45 kPa. A further increase of the vacuum level from 45 to 48 kPa caused no significant decrease of tMGG. Referring to this study, the working vacuum level of the MULTI, which was 3 kPa lower than vacuum level used in the CON, could have caused a longer tMGG because of slower milk removal from the udder and teat cistern. In general, it must be considered that vacuum as a factor cannot be viewed separately because the present study was designed as a comparison of two different systems. Technical parameters (vacuum, pulsation rate and ratio etc.) of both systems were used according to the indication of the manufacturers and were not changed during the trial period.

Sandrucci *et al.* (2007) ascertained a HMF of 3.8±1.2 kg/min which was in agreement with the findings of the present study. Higher values of HMF with 4.49 kg/min and DMG with 2.84 kg/min, in comparison with our study, were found by Strapák *et al.* (2009) at nearly the same level of MGG (15.63 kg). But our experiment showed that HMF, DMG as well as DMHG calculated for MULTI were significantly lower in comparison with cows milked conventionally, maybe caused by the lower working vacuum at MULTI. In this context, Ipema & Hogewerf (2004) found out that change of vacuum level or pulsation ratio did not significantly affect MGG in an automatic milking system (AMS). But raising the vacuum level from 42 to 45 kPa resulted in a 5 % higher DMG. Cows with high HMF are preferable for dairy farmers because of their shorter duration of milking (Klaas *et al.* 2005). But the targeted selection of cows with high HMF cannot be recommended without consideration of the negative effect in regard to increased risk for mastitis and hygiene problems (Boettcher *et al.* 1998, Klaas *et al.* 2005). Roth *et al.* (1998) was able to prove that cows with DMG as well as HMF between 3.5 and 4.0 kg/min had the lowest incidence of subclinical mastitis, which demonstrated that there is an individual optimal range for udder health. In comparison with the present study, both milking systems did not reach the values for DMG and HMF specified by Roth *et al.* (1998); only HMF (CON) reached the suitable milk flow class with 3.68 kg/min.

Persson Waller *et al.* (2003) ascertained that quarters with milk leakage had significantly higher mean and peak flow rates than quarters without leaking milk. They also found out that the risk for milk leakage was higher in AMS than in dairy groups using a conventional milking parlour with fixed milking intervals.

Considering the parity effect, Strapák *et al.* (2009) demonstrated that cows in the second lactation had the highest DMG (3.01 kg/min) and the highest HMF (4.96 kg/min), which is in agreement with our own examined values. In addition, we figured out that between first and second lactation a significant difference in regard to HMF existed. A high production level, as it is often the case with multiparous cows, has no influence on the course of milk ejection and milk flow. Therefore the milk flow of high-yielding cows is mainly characterized by a prolonged milking time, but not by an increase of HMF and DMG (Wellnitz *et al.* 1999).

DMG decreased slowly since the third month of lactation till month ten of lactation, maybe caused by increasing milk yield.

The time of increase in milk flow from 0.5 kg/min till reaching tPL was 0.53±0.34 min (MULTI) and 0.92±0.40 min (CON). The results showed that the milk letdown started earlier at the trial group milked quarter-individually. Sandrucci *et al.* (2007) described a short tAN (0.89±0.47 min) that showed a wide variability similar to the present results for cows milked conventionally. Pre-stimulation positively influences the parameters of milk flow and therefore the efficiency of milk removal (Tančin *et al.* 2007a). The tPL detected by Zucali *et al.* (2009) was on average 2.8±1.7 min and decrease phase (tAB) showed an excessive duration of 2.5±1.3 min, which was in line with results detected by Sandrucci *et al.* (2007). The results, detected during the trial period, showed that tPL as well as tAB was considerable longer in MULTI compared to CON. The similar duration of tPL and tAB for CON were a sign of a disadvantageous structure of the milking (Göft *et al.* 1994). It indicated an unbalanced milk secretion between the four udder quarters. Quarters with long tAB had higher SCC in comparison with quarters with shorter tAB (Tančin *et al.* 2007b).
Lactation did not influence tAN (Tančin *et al.* 2006), which is similar to the present findings. It could be concluded that problems with the milk ejection and removal, induced by the adaptations of cows to milking (Tančin & Bruckmaier 2001), did not occur in primiparous cows in this experimental trial which is a sign of good pre-milking steps. According to Naumann & Fahr (2000), the transition between tPL and tAB represented the moment on which the milk flow at least in one udder quarter has ended. The tAB is the time interval in which the full milking vacuum has an effect on one or more empty quarters (Tančin *et al.* 2007b). Especially front quarters needed usually less time for milking than rear quarters because rear quarters contain more milk (Rothenanger *et al.* 1995, Wellnitz *et al.* 1999).

One of the main objectives of the dairy industry is to minimize tMGG of a cow and, in the next step, to minimize tMGG of the whole herd to save labour costs, without affecting milk yield and udder health negatively (Lee & Choudhary 2006). It still has to be mentioned that no machine devices are presently suitable for reducing tAB, although longer tAB at quarter level could be considered as a critical point for incidence of udder diseases (Tančin *et al.* 2006). In general, there are three possibilities to affect the conditions of tAB and to avoid too long over-milking. Firstly, quarter-individual intermediate stimulation of teats for a faster and completely milking out during tAB. Another way is to detach single teat cups depending on quarter level milk flow. Until now, this possibility is only available for AMS, but it is unavailable for conventional milking parlours. Thirdly, a vacuum steering depending on quarter level milk flow can be used to reduce vacuum (switch to holding vacuum) on quarter level when single quarters reach the detachment threshold.

According to Göft *et al.* (1994) the trapezium shape of milk flow curve represents the optimal course of milk letdown which comprises a short and steep incline phase, a long plateau phase with a DMHG between 3 and 4.5 kg/min as well as a short and steep decline phase. In the present study only 2.2 % (MULTI) or 6.4 % (CON) of the curves showed such a type of milk flow which is a lower percentage than found by Wessels (2000) with 14.5 % or Roth *et al.* (1998) with 16.8 %. In this context, it may be useful to reflect if the aim of many breeders to breed cattle with a trapezium shape of milk flow curve stand for a physiological milk letdown, because most cows did not have such milk flow. Former studies (Roth *et al.* 1998) have also shown that the share of trapezium shapes is decreasing with increasing number of lactation. Due to the high number of cows with a gradual or continuous decline phase, it seems to be normally that single quarters are not milked out at the same time. Different quarter milking times were caused by uneven distribution of quarter milk yields (Wellnitz *et al.* 1999). Schöne *et al.* (1994) showed that front quarters needed less time for milking than rear quarters. The usage of quarter-individual milking technique could be intended to remedy this problem by single detachment of teat cups. Roth *et al.* (1998) also found out that the type of milk flow curve gives no evidence of the status of udder health in regard to SCC and bacterial findings. The low percentage of bimodality curves in the experimental group milked with MULTI was a sign of good pre-stimulation by actuator usage.

The present study was the first comparison between a quarter-individual (MULTI) and a conventional (CON) milking system installed in a conventional milking parlour. Most milk flow traits were significantly affected by milking system and by lactation number. A main finding of this experimental trial was that MGG and tAB in the MULTI were as good as in the CON. Quarter-individual milking, in the way it is executed by the MULTI, resulted in an abbreviated tAN which pointed out that pre-stimulation with the so called actuator is beneficial to the milking process. In contrast tMGG is longer in MULTI, maybe caused by lower vacuum level and periodic air inlet. Further research is needed to evaluate the effects of quarter-individual milking on the state of udder health. This included the detection of SCC, bacteriological status and milk ingredients as well as the inspection of teat condition. We conclude, that as far as the milkability of dairy cows is concerned, quarter-individual and conventional milking are equally acceptable for proper milking in milking parlours.

Acknowledgements

This study was supported by the German Federal Office for Agriculture and Food. The authors thank »Siliconform GmbH« for their kind help in providing the MultiLactor. Furthermore, we thank the staff of the »Landwirtschaftliche Produktions- und Handelsgesellschaft Remptendorf« for their friendly support throughout the experiments.

References

Boettcher PJ, Dekkers JC, Kolstad BW (1998) Development of an udder health index for sire selection based on somatic cell score, udder conformation, and milking speed. J Dairy Sci 81, 1157-1168

Bruckmaier RM, Hilger M (2001) Milk ejection in dairy cows at different degrees of udder filling. J Dairy Res 68, 369-376

Bruckmaier RM, Rothenanger E, Blum JW (1995) Milking characteristics in dairy-cows of different breeds from different farms and during the course of lactation. J Anim Breed Genet 112, 293-302

Dodenhoff J, Sprengel D, Duda,J, Dempfle L (1999) Studies on genetic evaluation of udder health using the LactoCorder. Züchtungskunde 71, 459-472 [in German]

Göft H, Duda J, Dethlefsen A, Worstorff H (1994) Studies on breeding use of milkability traits with regard to milk flow curves in dairy cattle. Züchtungskunde 66, 23-37 [in German]

Hamann J (1997) Guidelines for evaluation of the milking process. Int Dairy J/Bulletin of the IDF 321, 26-30

Ipema AH, Hogewerf PH (2004) Effects of milking machine parameters on the mean milk flow rate in a robotic milking system. Automatic milking: a better understanding. Conference Proceedings, Lelystad, Netherlands, March 2004, 450-456

Ipema AH, Hogewerf PH (2008): Quarter-controlled milking in dairy cows. Comput Electron Agric 62, 59-66

Kanswohl N, Schlegel M, Expósito GP, Rössel D (2007) Effect of different time of pre-milking teat preparation on milking characteristics of dairy cows in Cuba. Arch Tierz 50, 337-347 [in German]

Klaas IC, Enevoldsen C, Ersbøll AK, Tölle U (2005) Cow-related risk factors for milk leakage. J Dairy Sci 88, 128-136

Lee DH, Choudhary V (2006) Study on milkability traits in Holstein cows. Asian Australas J Anim Sci 19, 309-314

Mijić P, Knežević I, Domaćinović M (2004) Connection of milk flow curve to the somatic cell count in bovine milk. Arch Tierz 47, 551-556

Naumann I, Fahr RD, von Lengerken G (1998) Relationship between somatic cell count of milk and special parameters of milk flow curves of cows. Arch Tierz 41, 237-250 [in German]

Naumann I, Fahr RD (2000) Investigation of milk flow from udder quarters. Arch Tierz 43, 431-440 [in German]

Persson Waller K, Westermark T, Ekman T, Svennersten-Sjaunja K (2003) Milk leakage - an increased risk in automatic milking systems. J Dairy Sci 86, 3488-3497

Petrovski KR, Trajcev M, Buneski G (2006) A review of the factors affecting the costs of bovine mastitis. J S Afr Vet Assoc 77, 52-60

Pfeilsticker HU, Bruckmaier RM, Blum JW (1996) Cisternal milk in the dairy cow during lactation and after preceding teat stimulation. J Dairy Res 63, 509-515

Rittershaus C, Seufert H, Wolter W (2002) Milking routine analysis on farms with milking parlours. Proceedings of the 8th International Congress on Mechanization and Energy in Agriculture, Oct.15-17, 2002, Kusadasi, Turkey, 385-387

Rose-Meierhöfer S, Brunsch R, Jakob M (2009) Reduction of forces on the teats by single tube guiding in conventional milking parlours. SA Anim Sci 39, 161-164

Rose-Meierhöfer S, Hoffmann G, Öz H, Ströbel U, Ammon C (2010) Milking-time tests in conventional and quarter-individual milking systems. Landbauforsch Volk 60, 11-15

Roth S, Reinsch N, Nieland G, Schallenberger E (1998) Interrelationships between udder health, milking characteristics and milk flow curves in a high yielding dairy herd. Züchtungskunde 70, 242-260 [in German]

Rothenanger E, Bruckmaier RM, Blum JW (1995) Association and dissociation of single quarter and total milk flow in dairy cows: Effects of milking with and without prestimulation. Milchwissenschaft 50, 63-67

Sandrucci A, Tamburini A, Bava L, Zucali M (2007) Factors affecting milk flow traits in dairy cows: Results of a field study. J Dairy Sci 90, 1159-1167

Schöne A, Worstorff H, Göft H, Prediger A (1994) Experimental studies on the duration of the main milking time of udder quarters depending on cell number and lactose content. Milchwissenschaft 49, 427-432 [in German]

Strapák P, Sukenikova Z, Antalik P (2009) Milkability in Holstein cows. J Cent Eur Agric 10, 207-210

Tančin V, Bruckmaier RM (2001) Factors affecting milk ejection and removal during milking and suckling of dairy cows. Vet Med - Czech 46, 108-118

Tančin V, Ipema B, Hogewerf P, Macuhova J (2006) Sources of variation in milk flow characteristics at udder and quarter levels. J Dairy Sci 89, 978-988

Tančin V, Uhrincat M, Macuhova L, Bruckmaier RM (2007a) Effect of pre-stimulation on milk flow pattern and distribution of milk constituents at a quarter level. Czech J Anim Sci 52, 117-121

Tančin V, Ipema AH, Hogewerf PH (2007b) Interaction of somatic cell count and quarter milk flow patterns. J Dairy Sci 90, 2223-2228

Wellnitz O, Bruckmaier RM, Blum JW (1999) Milk ejektion and milk removal of single quarters in high yielding dairy cows. Milchwissenschaft 54, 303-306

Wessels U (2000) Characterization of the milking pattern of cows on farms in Schleswig-Holstein. Diss., University Kiel, Germany [in German]

Zucali M, Bava L, Sandrucci A, Tamburini A, Piccinini R, Dapra V, Tonni M, Zecconi A (2009) Milk flow pattern, somatic cell count and teat apex score in primiparous dairy cows at the beginning of lactation. Ital J Anim Sci 8, 103-111

Received 13 September 2010, accepted 13 January 2011.

Corresponding author:

Anika B. Müller
email: amueller@atb-potsdam.de

Department of Engineering for Livestock Management, Leibniz Institute for Agricultural Engineering, Potsdam-Bornim, Max-Eyth-Allee 100, 14469 Potsdam, Germany