The effect of various automatic cluster removal switch-point settings on milking and overmilking duration and on total, peak, and overmilking claw vacuum in dairy cows

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SUPPLEMENTARY FILE

Detailed Methodological descriptions

Experimental design

Dairy herd and study population

The study was conducted at the Experimental Farm of the University of Pretoria, South Africa (Hillcrest Campus) in an all-year-round calving herd of 77 lactating cows. Animals were fed total mixed rations (TMR). The cows were milked three times daily in a 10-point herringbone milking parlour with a low milk-line. A Waikato milking machine (New Zealand, LP) with an Afimilk (Afikim, Israel) advanced management system was used. The herd comprised 80 lactating Holstein cows, with an average daily milk yield of 34.2 kg and a bulk milk SCC of 328 10^3 cells/ml milk at the start of the trial.

The cow selection for the study involved udder palpation and teat size measurements. Udders were palpated to identify meaningful fibrosis and nodules in the udder parenchyma. Teat sizes were measured with a DeLaval apparatus shortly before milking, following milk let-down. Exclusion criteria for study animals included cows within 10 days post-calving and those within 60 days of drying-off at the start of the study, cows with udder fibrosis or nodules, and cows with teats equal to or shorter than 3 cm. A summary of exclusion data and parlour observations is provided (Table S1). Sixty-five cows were accessible for the study, of which 25 were randomly selected for the trial. For each switch-point setting, 25 cows' measurements were taken at morning milking for 15 consecutive days. The three switch-point settings were assessed in series with a three-day adaption period between the treatments.

Table S1. Summary of data excluded and parlour observations.

	Switch-point settings			**Total**	**Percentage of data excluded**
	0.504 kg/min	**0.630 kg/min**	**0.840 kg/min**		
Number of milkings evaluated (Tests performed)	15 (315)	15 (315)	15 (315)	45 (945)	
Reasons for data exclusions					
Wrong cows milked	8	9	8	25 (2.7%)	18.8%
Incomplete data	8	5	8	21 (2.2%)	15.8%
Liner slip	14	16	15	45 (4.8%)	33.8%
Kicked at end of milking	3	8	3	14 (1.5%)	10.5%
Vacuum failure (fall-off)	4	5	4	13 (1.4%)	9.8%
Leakage on VaDia pipes	4	3	6	13 (1.4%)	9.8%
Clinical mastitis	1	0	1	2 (0.3%)	1.5%
Total data excluded	**42**	**46**	**45**	**133 (14.1%)**	
Additional parlour observations					
Cows uncomfortable at end of milking (shift weight)	7 (2.2%)	18 (5.7%)	0	25 (7.9%)	N/A
Ring or slight swelling evitable on teat base after cluster removal	6 (1.9%)	7 (2.2%)	1 (0.3%)	14 (4.44%)	N/A

Validation and quality assurance

The milking machine was assessed (static and dynamic tests) just before the start of the study to ensure effective machine functioning. All milking machine settings, except the switch-point volumes, were consistent throughout the study. The duration of the milking phases (s) was A= 143, B = 538, C = 116 and D = 284, with 55 pulses/min. The milking (system) vacuum was 41.5 kPa, with a second-minute teat end vacuum of 34.2 kPa and an average vacuum fluctuation of 2.1 kPa for the average producers in the parlour. Non-vented, round 45mm teat liners (jetter cups) were used (Waikato Milking Systems, RMJ420, Skallerup Industries Ltd, New Zealand).

Parameters of automatic cluster removal settings

The pre-milk time indicating the minimum time of cluster attachment to the teat was set at 120 s. The delay setting controlling the time delay between the vacuum shut-off to the claw piece and the beginning of cluster removal time was 3.5 s. The sweep delay and interval to remove milk from the clusters were 0 s and 2.0 s, respectively. The ACR delay (F2) indicates the flow rate at which the milking would end. Between 0.200 kg to 0.220 kg of milk is released every time the cup of the flowmeter is filled, and its valve opens. In this study, 0.210 kg was used to complete the milk flow rate (MFR), calculated as follows:

$$\boldsymbol{MFR = \frac{60\ seconds}{F2\ Value} \times 0.210\ kg\ per\ minute}$$

For this study, the F2 settings of 15 s, 20 s and 25 s were chosen, which corresponded to ACR switch-points of 0.840 kg/min, 0.630 kg/min and 0.504 kg/min, respectively. The switch-point setting of 0.504 kg/ml was chosen as a starting point for the study as it was the current setting used in the experimental herd. The increased volumes were chosen based on research, identifying earlier take-off as more variable for preserving teat integrity (Edwards *et al.* 2013).

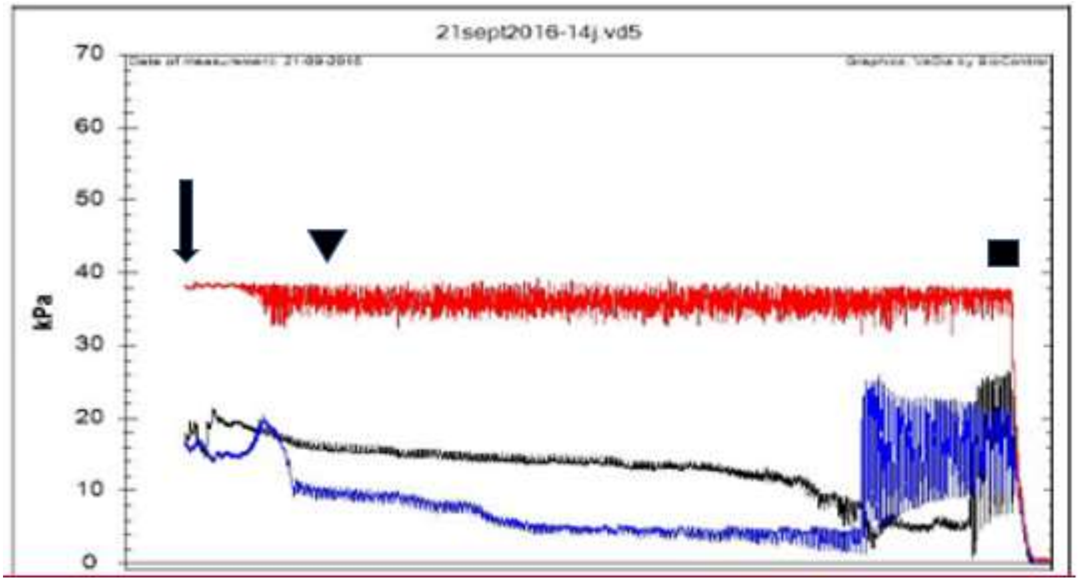
Milking parlour activities

Interpretive guidelines described by Moore-Foster *et al.* (2019) on parlour behaviour and milking dynamics were evaluated based on guidelines from the Teat Club International. The cows' milking events included the pre-lag time, second-minute milk flow, cow behaviour and events during milking. Clinical mastitis, vacuum loss, liner slip, cow comfort (shifting of weight), cluster fall-off, and cluster kick-off were recorded—the data were excluded from the final data set. Incomplete data of VaDia graphs (pipe damage, cows standing on the pipe, and unclear graphs) were excluded in the calculations.

VaDia Biocontrol measurements

Three VaDia units were calibrated before the study. In a pre-study trial, the results of the three VaDia units were compared for accuracy and precision. The VaDia apparatus measured vacuum in four channels. The VaDia Suite software graphically tabulates and illustrates these results (Biocontrol, Rakkestad, Norway). These measurements were taken at the mouthpiece chamber (MPC) of front and rear liners, a short milk tube (SMT) as a proxy for claw vacuum, and a short pulsator tube (SPT) as a proxy of the vacuum in the pulsator chamber. Bluetooth technology monitored the VaDia readings during milking. Data were downloaded with VaDia Suite software.

Guidelines and practical markers provided by Greenham (personal communication, March 2019) determined the following criteria: the start of milking (when vacuum first increased in any of the MPC or SMT); start of the incline phase of milk flow (almost simultaneous with the start of milking); start of overmilking and the end of milking (the point where all MPC and SMT traces return to the non-milking vacuum level or 0 kPa) (Figure S1). The start of overmilking was logged when the mean MPC vacuum increased by >50%; the MPC vacuum range increased by >50%. This pattern was maintained for the rest of the milking; this was the overmilking period. The marker was positioned at the start of this phase (Figure S1), according to the VaDia Suite software instructions.



Time (s)

Figure S1. Examples of a VaDia Biocontrol, digital recording indicating the starting point of overmilking for hind and front quarters of dairy cows**.**

For each milking of each cow, vacuum (kPa) was recorded on the vertical axis and time intervals (s) on the horizontal axis. Symbols mark the start of milking (⬇); start of peak milk flow (▼); start of overmilking 1 and 2 with vertical lines; and end of milking (■). Channel 1 (black) was connected to the rear mouthpiece chamber; Channel 2 (blue) to the front mouthpiece chamber; Channel 3 (red) to the short milk tube.

Statistical analyses

Generalised linear models (GLM) were applied to the cows with behavioural events, indicating cow discomfort from the cows milked per day. The Binomial distribution and the logit link function defined the transformation required to enable a linear model (Supplementary File). The predicted means were compared using Tukey's range test at a 5% significance level (Freund *et al.* 2010). The statistical software GenStat® (VSN International , 2019—Supplementary File) was employed for the data analysis.

The three ACR switch-point settings were compared for machine-on time, overmilking duration, total vacuum, vacuum at peak flow, and vacuum during overmilking. The Shapiro-Wilk test evaluated the normality distribution for each of the factors, which were not normally distributed for any of the variables evaluated (machine-on time, overmilking duration, total vacuum, vacuum at peak flow, and vacuum during overmilking) (Table S2). The non-parametric Kruskal-Wallis rank-sum test, therefore, compared the three ACR switch-point settings. The Kruskal-Wallis test indicated significant differences. This test was followed by the Wilcoxon rank-sum test to compare the variations of the separate groups (Benjamini & Hochberg, 1995) for machine-on time, overmilking duration, mean total claw vacuum, claw peak flow vacuum, and claw overmilking vacuum.

Supporting Results

Table S2. Summary of the peak milk flow (kg/min) for the three switch-point settings of a dairy cow milking machine.

	Switch-point settings		
Peak milk flow	**0.840 kg/min**	**0.630 kg/min**	**0.504 kg/min**
Average	2.83	3.00	2.96
Median	2.90	2.90	2.85
Minimum	0.20	0.20	0.20
Maximum	7.90	7.50	8.50
Standard deviation	1.23	1.21	1.40
Number of observations	307	309	324

Supporting literature

Introduction

According to Odorcic *et al.* (2019), short-term damage in the teat was mostly caused by circulation impairment and openness of the teat canal.

When set optimally, an ACR should maximise milking efficiency (cows milked per operator) (Edwards *et al*. 2013).

Machine-on time

Machine-on time reduction may lower the risk of teat canal damage (Neijenhuis *et al.* 2000) while reducing overmilking without harming milk production, milk components, or yields (Wieland *et al*. 2020).

As the ACR switch-point settings approached their optimal setting for the parlour, less improvement in machine-on time was observed (Magliaro & Kensinger, 2005). Stewart *et al.* (2002) established a greater machine-on time reduction (10.2 s to 15.6 s per cow) with increased milk flow.

Overmilking duration

These findings confirm that overmilking correlates with increased milking, while decreasing milking and parlour efficiency (Moore-Foster *et al.* 2019).

Recent studies using quarter milk flow patterns, provide more biological information to improve milking machine settings (Tančin *et al.* 2007).

Comparison of mean vacuums at peak milk flow and during overmilking

At the udder level, the end of the plateau phase is determined by the duration of the fastest milking quarter, whereas at the quarter level, it is determined by the availability of the milk in that quarter (Weiss *et al.* 2004).

Supplementary References

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