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Effect of mechanical premilking stimulation on milking duration in late lactation

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ABSTRACT

This study documents the effect of mechanical pre-stimulation on the milking duration of pasture-based cows in late lactation to better harness increased capacity of automation in the milk harvesting process. Premilking stimulation, provided via manual or mechanical means, has been shown to promote the milk letdown reflex and assist in achieving quick, comfortable, and complete milk removal from the udder. The literature is lacking knowledge on the effect of mechanical premilking stimulation on milking duration, especially in late lactation and in pasture-based systems, and many pasture-based farms do not practice a full premilking routine because of a lack of labor availability. The current study addresses this gap in knowledge. In this study, we tested 2 treatments: (1) the No Stim treatment used normal farm milking settings with no premilking preparation and (2) the Stim treatment used 60 s of mechanical premilking stimulation, with a rate of 120 cycles per minute and a pulsator ratio of 30:70 on cluster attachment. Once the 60 s of stimulation had elapsed, normal milking settings resumed for the remainder of the milking. Sixty cows were enrolled in the study, which ran for 20 d. The effect of treatment on a.m. milking duration was significant, a.m. milking duration for Stim was 12 s shorter than that of No Stim. The effect of treatment on p.m. milk duration was not significant. Treatment had no effect on a.m./p.m. milk yields, average milk flowrates or peak milk flowrates. Significant differences emerged between treatments on a.m. and p.m. dead time (time from cluster attachment to reach a milk flowrate of 0.2 kg/min). The a.m. and p.m. dead times were 6 s shorter for Stim compared with No Stim. The time taken to achieve peak milk flowrate (time to peak) at morning milking was 7 s shorter for Stim compared with No Stim, and treatment yielded no significant effects on time to peak at p.m. milkings. Treatment also had no significant effect on $\log_{10}$ somatic cell count. Although the percentage of congested teat-ends and teat-barrels was numerically lower for Stim versus No Stim, no statistical differences were detected across these measures. Based on the results of the study, we found merit in applying 60 s of mechanical pre-stimulation at a.m. milking from a milking duration perspective. However, the strategy was not as successful for the p.m. milking. Analysis of the milk flowrate profiles recorded during the study suggest potential utility in employing different machine settings for various milkings based on anticipated yield and level of udder fill.

Key words: milking, pulsation, milking duration, milk flowrate

INTRODUCTION

Although varying degrees of udder preparation commonly practiced in indoor systems can aid in stimulating oxytocin release and milk letdown, minimum udder preparation is typically practiced in pasture-based systems common in Ireland and New Zealand. This may result in bimodal milk flowrate profiles due to delayed oxytocin release and subsequent milk letdown after cluster attachment (Bruckmaier and Blum, 1996) with possible deleterious effects on milk yield, milking duration, and udder health.

The risk of these deleterious effects following cluster attachment is greatest during the period of the lactation with low yields because of a large proportion of milk being alveolar in nature when yield reduces (Bruckmaier and Blum, 1998). In contrast to cisternal milk, which is immediately available for collection, alveolar milk needs the action of oxytocin to expel it from the gland (Costa and Reinemann, 2004). Oxytocin release usually follows appropriate stimuli, which can include tactile or mechanical stimulation.

Work investigating the use of mechanical premilking stimulation has been conducted since the 1970s by Sagi et al. (1980), but most has been conducted on intensive indoor systems. In such systems, tactile stimulation occurs by default as a result of more demanding premilking udder preparation protocols required for milk

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Table 1. Average parameters of the cows used on the study

Item	Minimum	Mean	Maximum	SD
Daily milk yield (kg)	8.7	14.3	21.6	3.1
Daily milk duration (min)	6.8	10.0	14.1	1.9
Average milk flowrate (kg/min)	0.8	1.5	2.4	0.3
DIM	215	256	282	16.1
Parity	1.0	3.0	8.0	1.6

hygiene purposes. Edwards et al. (2013a) applied 30 s of mechanical stimulation in a pasture-based system. However, this study was conducted during peak production, and the benefits of premilking stimulation are likely greatest later in lactation (Sagi et al., 1980; Weiss and Bruckmaier, 2005).

With the trend for increased herd size not matched by a proportional increase in labor availability, more automation has been employed in the milking process. Mechanical stimulation could be used in place of tactile stimulation to trigger oxytocin release. This stimulation is usually an increased pulsator rate for a period immediately after cluster attachment to elicit a vibration effect on teat tissue before typical milking pulsator settings are applied. Where applied, it has usually been at the default settings of the manufacturer as opposed to a more dynamic approach based on milk flow. A proprietary technology has been used in several studies based on a 300-cycles-per-minute pulsator rate at reduced pulsation chamber vacuum (Edwards et al., 2013a; Watters et al., 2015). Pulsation settings can also be changed for the same purpose in standard milking systems (Sagi et al., 1980). The overall objective is to reduce the milking process time, while protecting teat condition and udder health without affecting milk yield.

Previous work on the use of mechanical premilking stimulation predominantly focused on intensive indoor systems, and work on pasture-based systems has mainly been conducted during peak lactation. The objective of this study, therefore, was to document the effect of mechanical prestimulation on the milking duration of pasture-based cows in late lactation to better harness the increased capacity of automation in the milk harvesting process.

MATERIALS AND METHODS

This study was carried out at the Teagasc Research Centre at Moorepark, Ireland. A mid-line 30-unit Dairymaster herringbone, swing-over milking system (Dairymaster, Ireland) was used to milk the cows on the trial twice per day. This simultaneous pulsation (4×0) milking system was fitted with automatic cluster removers and weigh-all milk meters (Dairymaster). The milk flowrate switch point of the automatic cluster removers was 0.2 kg/min with a 3 s time delay, which was the standard setting on the farm. The milking cluster weight was 2.8 kg, and it was fitted with 916SL milking liners. The milking parlor was modified to include one pulsator per cluster and equipped with automatic cow identification to facilitate the application of the correct treatment to each cow. The milking management software was modified to apply a predefined period of mechanical premilking stimulation to a particular cow at a defined pulsator rate and ratio after the cluster was attached and before the main milking period began. Milking duration in this study equated to cluster on time and included any stimulation period applied. The milking management software also recorded the milk flowrate from each cow at every milking at 10 s intervals (referred to as milk flowrate profiles). This study was conducted with approval of the Teagasc Animal Ethics Committee (TAEC; TAEC2020–249) and in accordance with the Cruelty to Animals Act (Ireland 1876, as amended by European Communities regulations 2002 and 2005) and the European Community Directive 86/609/EC.

Cow Selection

Cows eligible for inclusion in the trial had to have a milk SCC of less than 250,000 cells/mL at a weekly milk recording for 2 wk before the start of the study and 4 functional quarters. Of the eligible cows, 60 were selected for the study at random. Sample size was determined to detect a 10 s difference in milking time based on previously collected data. Of the cows selected, 46 were Holstein Friesian, and 14 were Jersey crossed with Holstein Friesian. Cows were an average of 256 DIM (range 215–282 DIM) at the beginning of the study. Average parity was 3, ranging from 1 to 8. The main cow-related parameters are presented in Table 1. Cows were blocked by breed and parity and randomly assigned to 1 of 2 groups (i.e., each group had 30 cows). Given farm management constraints the a.m.:p.m. milking interval was 16:8; therefore, average a.m. milk yields were higher than average p.m. milk yields.

Experimental Treatments

Two treatments were used. The control treatment (**No Stim**) deployed a milking pulsator rate of 60 cycles per minute and a ratio of 65:35 (a, b, c, and d phases of pulsation were 103, 547, 92, and 258 ms, respectively). The second treatment (**Stim**) used 60 s of mechanical premilking stimulation, with a pulsator rate of 120 cycles per second and a ratio of 30:70 (a, b, c, and d phases of pulsation were 98, 52, 88, and 262 ms, respectively) on cluster attachment before the main milking period, similar to Sagi et al. (1980). Once the 60 s elapsed, the control milking settings were applied for the remainder of the milking. The milking system vacuum was set at 47 kPa, which was common to both treatments. No premilking udder preparation was carried out by the farm staff for the duration of the study on either treatment.

Experimental Design

A crossover design was implemented whereby all cows received each treatment. In period 1 (first 10 d of the study), group 1 received No Stim, and group 2 received Stim. In period 2 (second 10 d of the study), group 1 received Stim, and group 2 received No Stim.

The teats of each cow were assessed after the a.m. milking, on one occasion per period, by the same trained observer. Teats were scored for teat-end congestion (scored as normal or firm) and ringing at the base of the teat (scored as normal or ringed), according to the method described by Mein et al. (2001).

A milking time test was carried out using a VaDia device (BioControl) on 2 occasions during the study (once per period) to record short milk-tube vacuum (V_{SMT}), mouthpiece chamber vacuum (V_{MPC}), and pulsation chamber vacuum (V_P) during the milking of 24 cows (12 per treatment). This was the maximum number of cows that could be recorded with the available devices.

Data Processing

Standard milking data were downloaded from the farm management software via spreadsheets: a.m. and p.m. milk yields (kg), milk duration (time from cups on to cups off, in seconds), average milk flowrate (**AMF**, kg/min), and peak milk flowrate (**PMF**, kg/min). Nonstandard milking variables were computed from the milk flowrate profiles (recordings of yield at 10 s intervals). These variables were a.m. and p.m. dead time (time from cluster attachment to reach a milk flowrate of 0.2 kg/min, recorded in seconds) and a.m. and p.m. time to peak (time from cluster attachment to reach PMF, in seconds). Milk flowrate profiles were imported to SAS 9.4 (SAS Institute Inc.), and the percentage of yield harvested for each decile of the milking (milking duration was divided in 10 equal duration portions) was plotted for each treatment for a.m. and p.m. milkings. A sample of milk was taken from each cow once weekly for composition and SCC analysis via a Fossomatic machine (Foss). The SCC data were log-transformed ($\log_{10}$) for subsequent analysis. All data were combined in SAS (SAS Institute Inc.). Milking durations of less than 123 s were removed from the data set; this was the delay time set on the milking machine above which the cluster removers could be activated. Milkings with a yield of less than 1 kg were removed. This filtering removed less than 1% of data points from the data set. The first 2 d of each period were also removed from the data set to minimize carryover effects.

The teat scoring data were recorded manually in the parlor and transferred to spreadsheets. In addition to each quarter level teat-end score (TE), each cow received an overall cow level teat-end score (TEC) of normal (N) or firm (F). A TEC score of F was recorded if one or more of the individual teat-ends were firm on the day of recording.

Similarly, in addition to each quarter level teat-barrel score (TB), each cow received an overall cow level teat-barrel score (TBC) of normal (N) or ringed (R). A TBC score of R was recorded if one or more of the individual teat-barrels were ringed on the day of recording.

Statistical Analysis

Milking Data. A generalized linear mixed model was used to analyze the effect of the treatments on various dependent variables using the MIXED procedure in SAS 9.4 (SAS Institute Inc.) as follows:

$$y = \text{Treatment} + \text{Block} + \text{Period}, \qquad [1]$$

where y = milking duration (primary outcome measure), milk yield, AMF, PMF, and $\log_{10}$ SCC; Treatment = Stim or No Stim; Block = block number based on parity and breed; and Period = first or second 10 d of the study. Treatment, Cow, Period, and Block were declared as class variables. Cow was defined as a random variable and a repeated measure. The ar(1) covariance structure was specified. Period in Equation 1 was not significant ($P > 0.05$) and was removed from the model yielding the final model:

$$y = \text{Treatment} + \text{Block}. \qquad [2]$$

Teat Scoring Data. A generalized linear model was used to analyze the effect of treatment on the TEC and

TBC score of the cows using the GENMOD procedure in SAS (SAS Institute Inc.) as follows:

$$y = \text{Treatment} + \text{Block} + \text{Period}, \quad [3]$$

where y = TE, TB, TEC, or TBC; Treatment = Stim or No Stim; Block = block number based on parity and breed; and Period = first or second 10 d of the study. Treatment, Cow, Quarter, Period and Block were declared as class variables. Quarter within Cow was defined as a repeated measure. Block and Period were not significant in any instance of y ($P > 0.1$) and were removed from the model yielding the final version as

$$y = \text{Treatment}. \quad [4]$$

RESULTS

Effect of Treatment on Milking Variables

The effect of treatment (mechanical pre-stimulation) on a.m. milking duration was significant ($P = 0.04$); a.m. milk duration for Stim was 12 s shorter than that of No Stim (Table 2). The effect of treatment on p.m. milking duration was not significant. Similarly, treatment resulted in no effect on a.m./p.m. milk yields, a.m./p.m. AMF, or PMF.

Significant differences emerged between treatments on a.m. and p.m. dead time, which were 6 s shorter for Stim compared with No Stim ($P < 0.001$ for a.m. and $P = 0.004$ for p.m.).

The a.m. time to peak flowrate was 7 s shorter for Stim compared with No Stim ($P = 0.05$), and treatment had no significant effect on time to peak at p.m. milkings.

No significant effect of treatment was recorded on log SCC ($P = 0.78$). The back transformed SCC values were 69,000 and 68,000 cells/mL for the No Stim and Stim treatments, respectively.

Effect of Treatment on Teat Congestion

Although the percentage of congested teat-ends was numerically lower for Stim versus No Stim (39% vs. 45% of teats scored as firm, respectively) and TEC was slightly lower for Stim versus No Stim (70% vs. 73% of cows scored as firm, respectively), no significant differences were detected across these measures (Table 3).

Similarly, the number of congested teat-barrels were numerically lower for Stim versus No Stim (12% vs. 13% of teats scored as ringed, respectively) and TBC was slightly lower for Stim versus No Stim (30% vs. 34% of cows scored as ringed, respectively). No significant differences were detected across these measures (Table 3).

Table 2. Main milking parameter results by treatment[1]

Item	No Stim	Stim	P-value
a.m. milk duration (s)	350	338	0.04
p.m. milk duration (s)	232	234	0.52
a.m. milk yield (kg)	9.31	9.28	0.87
p.m. milk yield (kg)	3.96	3.94	0.81
a.m. average flowrate (kg/min)	1.84	1.81	0.42
p.m. average flowrate (kg/min)	1.32	1.23	0.13
a.m. peak flowrate (kg/min)	2.85	2.84	0.76
p.m. peak flowrate (kg/min)	2.21	2.20	0.82
Dead time a.m. (s)	29.3	23.3	<0.0001
Dead time p.m. (s)	45.1	38.6	0.004
Time to peak a.m.	175	168	0.05
Time to peak p.m.	128	129	0.52
Log SCC[2]	1.84	1.83	0.78

[1]No Stim = control treatment with a milking pulsator rate of 60 cycles per minute and a ratio of 65:35; Stim = 60 s of mechanical premilking stimulation, with a pulsator rate of 120 cycles per second and a ratio of 30:70.

[2]Log-transformed SCC.

DISCUSSION

Mechanical pre-stimulation significantly reduced the milking duration of a.m. milkings ($P = 0.04$) but not p.m. milkings ($P = 0.52$). The difference in outcome across a.m. and p.m. milkings is likely a result of the uneven milking interval deployed on the farm: 16 h between p.m. and a.m. milkings but only 8 h between a.m. and p.m. milkings. This interval was imposed because of staffing restrictions on the farm. The uneven milking interval resulted in large variations in yield harvested (9.3 kg a.m. vs. 3.95 kg p.m.) and hence milking durations (344 s a.m. vs. 233 s p.m.). Furthermore, the portion of total milking duration taken up by dead time at the beginning of milking was higher for p.m. milkings (18% dead time) than a.m. milkings (8% dead time).

Table 3. Teat scoring results for teat-end and teat-barrel congestion by treatment[1]

Item[2]	No Stim (%)	Stim (%)	P-value
TEC	73	70	0.31
TE	45	39	0.17
TBC	34	30	0.88
TB	13	12	0.86

[1]No Stim = control treatment with a milking pulsator rate of 60 cycles per minute and a ratio of 65:35; Stim = 60 s of mechanical premilking stimulation, with a pulsator rate of 120 cycles per second and a ratio of 30:70.

[2]TEC = percentage of cows with at least one teat-end scored as firm; TE = percentage of teats scored as firm; TBC = percentage of cows with at least one teat-barrel scored as ringed; TB = percentage of teat-barrels scored as ringed.

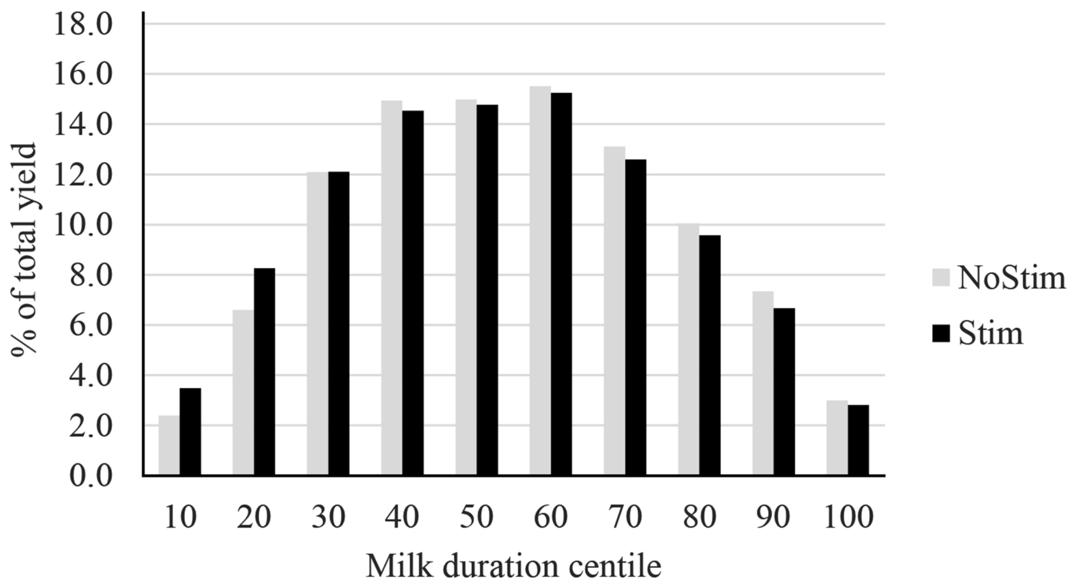

Figure 1. Percent of total milk yield harvested over time for a.m. milkings across treatments. No Stim = control treatment with a milking pulsator rate of 60 cycles per minute and a ratio of 65:35; Stim = 60 s of mechanical premilking stimulation, with a pulsator rate of 120 cycles per second and a ratio of 30:70.

This results in very different milk flowrate profiles for a.m. and p.m. milkings (Figures 1 and 2) and suggests potential utility in employing different machine settings for various milkings based on anticipated yield, in agreement with Weiss and Bruckmaier (2005). From this perspective, testing different mechanical stimulation durations based on different milking intervals would be interesting. Similarly, the ability to begin milking with a low vacuum followed by a higher vacuum during peak flow may be beneficial in this context. These flow-controlled vacuum systems were evaluated previously by Reinemann et al. (2021), but not from a low udder fill perspective specifically. Furthermore, reductions in occupancy time (defined as time from the first touch of the udder until cluster detachment) was considerably shorter in treatments utilizing reduced pulsation (pulsation ratio 30/70, pulsation rate 50 cycles/min, claw vacuum 44 kPa) and reduced pulsation and vacuum (pulsation ratio 30/70, pulsation rate 50 cycles/min, claw vacuum 34 kPa) at the beginning of milking, relative to treatments where manual pre-stimulation was carried out (Tuor et al., 2022), although no differences were noted in postmilking teat thickness.

The most comparable study in the literature was carried out by Sagi et al. (1980), which applied 60 s of fast pulsation at the beginning of milking (pulsator rate of 120 and ratio of 30:70) on cows in late lactation. A machine-on time increase of 0.5 min (7.7%) was reported for the fast pulsation treatment relative to a no stimulation treatment. This is contrary to the results of this study, where we reported a 1.7% reduction in machine on time for the Stim treatment versus the No Stim treatment.

The results of the study of Edwards et al. (2013a) detected no significant difference for machine-on time where 30 s of mechanical stimulation was applied. However, that study was conducted during peak lactation where a high degree of udder fill and consequently, a high proportion of cisternal milk would be anticipated. A small difference in cluster on time was found in that study when tactile stimulation was applied through the removal of 2 squirts of foremilk from each quarter. However, when a similar tactile stimulation was applied toward the end of the previous lactation (Edwards et al., 2013b), the reduction in cluster on time was double this level. No mechanical stimulation treatment was applied in their late lactation study.

A study by Watters et al. (2015) applied mechanical premilking stimulation of 0, 30, and 90 s on cows milked 3 times a day using 300 pulsation cycles per minute with a pulsation chamber vacuum of 20 kPa. They noted that cluster on time fell significantly (17 s, 6.5%) where 90 s of stimulation was applied relative to 0 s. However, they did not include the stimulation period in defining cluster on time. The significance of this results in an increased net procedure time (time under high vibration stimulating pulsation and normal milking pulsation) of 73 s.

A further relevant study by Weiss and Bruckmaier (2005) applied a mechanical premilking stimulation

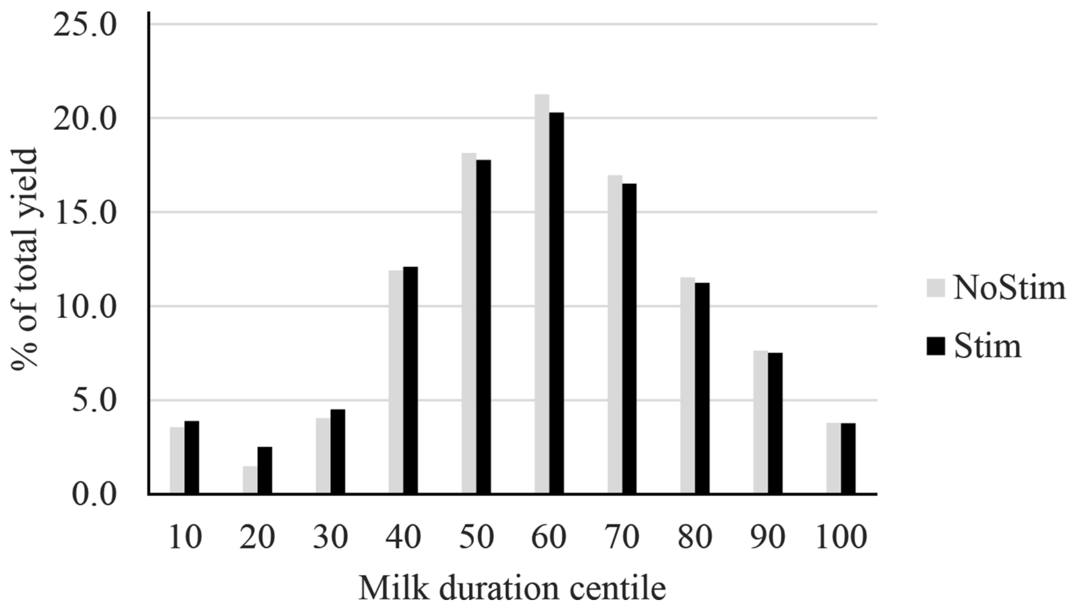

Figure 2. Percent of total milk yield harvested over time for p.m. milkings across treatments. No Stim = control treatment with a milking pulsator rate of 60 cycles per minute and a ratio of 65:35; Stim = 60 s of mechanical premilking stimulation, with a pulsator rate of 120 cycles per second and a ratio of 30:70.

varying in duration from 0 s to 90 s at a pulsation vacuum of 24 kPa and a pulsator rate of 300 cycles per minute. They noted that total machine-on time increased as stimulation was added. They also noted increased average flowrates with longer duration of mechanical stimulation, but the latter was calculated over the main milking time (excluding the stimulation period).

Figures 1 and 2 allow exploration of the percentage of milk harvested in each tenth of milking of the cows. For morning milkings, roughly 91% of milk could be harvested within 80% of the milking duration (Figure 1). This graphical representation allows comparison of milkings of different durations by standardizing them per decile of milking. Despite extensive study of bimodal milking and the proportion of milk harvested during the first 2 min of milking as documented by Watters et al. (2015), much less focus has been placed on studying the entirety of the milk flow profile. The analysis contained in this study can provide a useful tool to assess at which stage of the milking the benefits of a particular milking management strategy are clearer. This study suggests that the major gains by applying mechanical pre-stimulation are during the first half of milking by improving the milk let-down, which is supported by the literature.

The levels of teat-end firmness and teat-barrel ringing observed in this study were above recommended levels. The incidence of both teat-barrel ringing and teat-end firmness should be below 20% of cows in a herd and below 8% of overall teats within a heard, to promote good udder health (Reinemann et al., 2001; DairyNZ, 2012). The main contributing factors behind the high levels of teat congestion (i.e., teat-end firmness and teat-barrel ringing) observed in this study (Table 3) were likely as follows: (1) The stage of lactation of the cows (average 256 DIM) resulted in very low milk yields and hence very low average milk flowrates (Table 2), especially during the p.m. milking. (2) The cluster removal settings of 0.2 kg/min were likely set too low to promote the reduction of congestion build-up at the end of milking. Increasing the cluster removal setting could result in a reduction of short-term changes in teat tissue condition (Wieland et al., 2020). (3) High V_{MPC} during milking or overmilking can result in increased levels of teat-barrel congestion. A study by Penry et al. (2017) observed that high levels of teat-barrel congestion should be avoided, because congestion can decrease teat canal area in a similar manner to teat-end congestion, which, in turn, decreases milk flow rates. A recommended V_{MPC} of <20 kPa during peak milk flow was mentioned by Rasmussen et al. (2007). In our study the V_{MPC} for No Stim was 2.6 kPa above this recommendation, but the V_{MPC} for Stim was 2.8 kPa below this level, which was an additional advantage of the Stim treatment.

Though not statistically significant, a reduction in incidence of teat-barrel ringing ($P = 0.86$) and teat-end firmness ($P = 0.17$) corresponded with a significant reduction in dead time for cows on the Stim treatment.

Table 4. Summary of data from the VaDia (BioControl) milking time test on a sample of 24 cows (12 per treatment) carried out at a.m. milking only[1]

Item[2]	No Stim	Stim	Difference (No Stim – Stim)
Milking duration (s)	367	343	24
Let-down time (s)	18	30	–12
Milk time (s)	291	255	36
Overmilking time (s)	33	22	11
V_{SMT} milk (kPa)	36.4	35.6	0.76
V_{SMT} overmilking (kPa)	41.6	41.2	0.31
V_{MPC} milk (kPa)	22.6	17.2	5.34
V_{MPC} overmilking (kPa)	29.2	27.1	2.10

[1]No Stim = control treatment with a milking pulsator rate of 60 cycles per minute and a ratio of 65:35; Stim = 60 s of mechanical premilking stimulation, with a pulsator rate of 120 cycles per second and a ratio of 30:70.

[2]V_{SMT} = short milk tube vacuum; V_{MPC} = mouthpiece chamber vacuum.

These observations make physiological sense when viewed in tandem with the milking time test results from the VaDia device (Table 4). The mouthpiece chamber vacuum during the main milking period (V_{MPC} milk of 22.6 kPA for No Stim vs. 17.2 kPA for Stim), mouthpiece chamber vacuum during the overmilking period (V_{MPC} overmilking of 29.2 kPA for No Stim vs. 27.1 kPa for Stim), and overmilking time (overmilking of 33 s for No Stim vs. 22 s for Stim) were all reduced when mechanical stimulation was applied, which may have contributed to the slight numerical reduction in instances of teat-barrel ringing and teat-end firmness.

These observations provide encouragement for further investigation employing premilking mechanical stimulation in the absence of tactile stimulation to test if significant improvements in both milking duration and teat condition can be achieved.

CONCLUSIONS

Based on the results on the study, we found merit in applying 60 s of mechanical pre-stimulation at morning milking from a milking duration perspective, but the strategy was not as successful for evening milking. Analysis of the milk flowrate profiles recorded during the study suggest potential utility in employing different machine settings for various milkings based on anticipated yield and level of udder fill.

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