Journal of Dairy Research (2006) **73** 187–192. © *Proprietors of Journal of Dairy Research 2006*
doi:10.1017/S002202990500155X *Printed in the United Kingdom*

The effect of pre-milking teat-brushing on milk processing time in an automated milking system

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Received 28 February 2005 and accepted for publication 31 August 2005

Cow throughput in an automatic milking system (AMS) is limited by system parameters such as the time required for pre-milking udder preparation and cup attachment, physiological responses of the cow (such as milk let-down and milking-out rate), milking machine features and cow behaviour. A single-factor cross-over design was used to investigate the effect of pre-milking teat brushing on milk processing time in an AMS operating in an extensive grazing farming system. Teat brushing consisted of two roller brushes tracking up each teat three times (total brushing time of up to 45 s/cow). Cows were allocated to one of two treatment groups with either no brushing (NB) or brushing (B) for a 4-week period before being changed to the other treatment. Teat brushing resulted in shorter average cups-on-time (B=506·1 s, NB=541·0 s, P=0·0001), longer average milk processing time (B=10·30 min, NB=9·76 min, P=0·001) and no difference in daily milk yield (B=14·67, NB=14·71 kg/cow, P=0·826). There was no difference between the two treatments in the success of cup attachment (B=3·76%, NB=5·10% unsuccessful milking attempts, P=0·285). The estimated time cost of pre-milking teat brushing was 53 min for every 100 milkings, equivalent to an additional 5–6 milkings for every 100 milkings by an AMS. The importance of these potential time savings is discussed in relation to automatic milking in farming systems that aim for a lower per cow milking frequency and high ratio of cows to AMS.

Keywords: Automated milking, grazing, cow throughput.

There has been a growing interest in developing a means of incorporating automated milking systems (AMS) into pastoral dairying systems such as those in New Zealand (Jago & Woolford, 2002; Jago et al. 2002; Woolford & Jago, 2002). Maximizing the milk harvested per AMS for minimum labour input is likely to be critical to the economic viability of a high-cost milk harvesting technology such as automatic milking in low-cost pastoral dairying environments. The current philosophy of New Zealand's robotic milking research programme (The Greenfield Project) has been to maximize the daily harvest of milk per AMS by reducing milking frequency and increasing the number of cows milked per AMS (Woolford et al. 2004).

Milking intervals and routines in AMS are considerably different from those in conventional milking systems. Milkings are performed almost continuously throughout a 24-h period and cow visits to the AMS are largely voluntary and unassisted. Pre-milking preparation of the udder and teats is automated and routine practice in all AMS (Knappstein et al. 2004). A variety of systems is used to clean the teats either sequentially or simultaneously before milking. These include twin counter-rotating brushes or rollers, a specially designed cup that is attached for cleaning and drying, or the same milking teat cup that performs a dual cleaning and milking function. Pre-milking udder preparation is routine practice in the EU (a requirement according to Council Directive 89/362/EEC) and serves to clean the teats and reduce the bacterial contamination of milk (Knappstein et al. 2004). It also serves to induce oxytocin release thus initiating milk ejection (Macuhova & Bruckmaier, 2000). It may also improve cup attachment, as teats are firmer following milk ejection (through increased intramammary pressure) and the cow may become better positioned in the milking stall prior to teat cup attachment.

In contrast, udder preparation prior to milking is not routinely carried out on New Zealand dairy farms although highest quality milk is still harvested. Early studies in the 1950s showed a significant production response to pre-milking manual stimulation of the udder and teats (Whittlestone et al. 1957; Phillips, 1958); however, later studies (Phillips, 1986) found that the effects were much reduced. Phillips (1986) suggested that farmer selection

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against cows with high requirements for udder stimulus had reduced the threshold value for triggering the milk ejection reflex. The same study also suggested breed differences as the New Zealand Jersey cow of the mid-1970s showed a greater response to stimulation than did the Friesian or Friesian × Jersey breeds of the same period. Recent studies have shown a faster milking speed for New Zealand Holstein Friesians compared with North American Holsteins (Kolver et al. 2000) although in other studies the differences in milking speed have been small (Petersen, 1988; Harris & Kolver, 2001).

In any AMS, milk production per milking unit is limited by cow throughput. Typically, 5–8 cow milkings/h are achieved in a single-box AMS depending on AMS features and stage of lactation (Wendl et al. 2000; Sangiorgi, 2002). During 2001 and 2002 a rate of 6 cows/h was regularly achieved at peak visiting times to the AMS with the pasture-based Greenfield herd (Hamilton, New Zealand) with a mean milking time (from entry to exit of AMS) of 9 min 3 s ± 57 s (Jago et al. 2002). Pre-milking teat brushing has been observed to take approximately 45 s/cow when using twin counter-rotating brushes, depending on the schedule selected. A reported lack of need for pre-milking stimulation among New Zealand cows (Phillips, 1986) would suggest that direct attachment of the teat cups without pre-milking stimulation/brushing has the potential to decrease overall milk processing time per cow milking.

The aim of this study was to determine the effect of pre-milking teat brushing on cup attachment, milking time and production for New Zealand cows milked in an AMS. The outcomes of the study potentially allow for more efficient utilization of the milking crate and consequently an increased number of cow milkings per AMS.

Materials and Methods

Experimental design

A single-factor cross-over design was used. Seventy-six New Zealand mixed-breed (Friesian, Friesian × Jersey, Jersey, Ayrshire), pasture-fed, mixed-age lactating dairy cows were allocated to one of two groups (Group 1 or Group 2) which were balanced for yield and stage of lactation. Sixty-three cows remained in milk for the entire data collection period. The trial was carried out over an 8-week period (23/01/03–20/03/03) with 4 weeks per treatment. The period length required to detect a 10% difference in milk processing time was determined prior to the study using milking data from 71 cows with residual maximum likelihood (REML) analysis to obtain between-cow, and between-week/within-cow variance components. Prior to the trial start date the herd average daily milk yield was 14·5 kg/cow and the average days in milk were 143 ± 14. Group 1 received no pre-milking teat brushing (NB) for the first 4 weeks and teat brushing (B) for the final 4 weeks, and *vice versa* for Group 2.

Milking procedure

The herd was milked in a single stall Fullwood Merlin® AMS. Pre-milking brushing consisted of a set of horizontally mounted, counter-rotating teat brushes rolling up and down each teat three times. Teats were brushed for a total of approximately 45 s/cow and the time from the start of brushing until the start of cup attachment was approximately 60 s. The delays between teat preparation and attachment are consistent with the recommendations of Rasmussen et al. (1992) in order to achieve maximum effect of pre-milking udder stimulation. All cows had had previous experience with the brushing treatment in a previous lactation.

Animal management

Cows were grazed as a single herd for the entire trial period. The minimum milking interval was set at 9 h and determined for individual cows using production rate and expected yield criteria (cows were generally not permitted to return to the dairy less than 9 h after previous milking) in an attempt to achieve an actual milking frequency of 1·1–1·5 milkings/cow per day. The production rate and expected yield criteria to achieve the minimum milking intervals were set as milking criteria in the Crystal software (Crystal 0.44, Fullwood Fusion, Willem Alexanderweg 83, 3945 CH Cothen, The Netherlands). The farm was set up as described by Jago et al. (2002) and included a system for remotely selecting cows for milking at pasture (Jago et al. 2004) with a fresh break of pasture being made available at 08.00 and 20.00 each day.

Key measurements

For the process of teat brushing, no sensory searching for the udder takes place by the AMS robotic arm. Instead the roller brushes use the stored co-ordinates from previous milkings to determine the location of the teats. As a result there is the potential for the cow to stand off to one side or for her udder confirmation to change vastly between milkings owing to variable intervals between milkings (9–24 h) and this can result in roller brushes missing the teats. To determine the actual contact time of the roller brushes with the teats, observations were carried out on a sample of milkings during each treatment period. The pre-milking teat brushing procedure was observed at least twice for each cow over each 4-week treatment period. During these observations a record was made of the extent to which the brushes rolled up each teat. A positive brushing was defined as the brushes rolling at least half way up the teat for each of the three occasions. The behaviour of the cows was also observed with the number of leg lifts recorded during both the brushing phase and the attachment phase of the milking. A leg lift was recorded every time a cow's foot was lifted from the floor of the AMS crate. A kick was defined as any leg lift combined with a sharp lateral movement in any direction. The completion of the cup attachment phase was defined as when all four teat cups were attached.

Key responses measured in this study were the total milk processing time (duration from entry into AMS crate until exit following milking), cups-on-time (time from attachment of first cup to removal of last cup), dead time (time from cup attachment to detection of milk flow for individual quarters of each cow at each milking) and milking time (calculated from time of first detected milk flow to time of cup removal, for each quarter of each cow at each milking). All measurements, except milking time, were automatically collected by Crystal (Crystal 0.44) or logview – the support software for the Fullwood Merlin AMS (Fullwood Ltd, Ellesmore, Shropshire, UK). Milking outcome (unsuccessful, <20% of expected yield harvested; yield carry over (YCO), 20–80% of expected yield harvested; OK, >80% expected yield harvested), milking interval and yield (kg) were also collected automatically using this software. An unsuccessful milking resulted in the cow being returned to the yard for another milking. This was generally caused by one or more cups failing to be attached to the teat (for various reasons including cow behaviour and machine problems) or by premature removal of cups. If the milk yield was high enough to result in a YCO or OK outcome then the cow was allowed to return to the paddock as she exited the AMS crate. A YCO resulted in a cow being allowed to return to the dairy earlier for another milking than her minimum milking interval as expected yield criteria had not been met.

Statistical analysis

Of the original 76 cows assigned to a treatment, 13 were dried off during the data collection period, therefore all results presented are from the 63 cows that remained in milk for the entire data collection period. The milking behaviour data were not normally distributed, therefore a square root transformation was applied to the number of leg lifts during the attachment phase of milking prior to carrying out an ANOVA using Genstat (2002, Genstat for Windows, release 6.1, 6th edition, VSN International Ltd, Oxford, UK). The number of kicks during cup attachment was not statistically analysed owing to the low incidence of this behaviour.

The proportion of unsuccessful milking attempts (<20% of expected yield harvested) was calculated for each cow for each period and analysed using ANOVA after an angular transformation because of heterogeneity of variance (ang(%)+arcsine(sqrt(%/100))). All data analyses for duration and yield parameters excluded unsuccessful milkings.

Total milk processing time (min/milking), cups-on-time (s/milking), milk yield (kg/milking), daily milk yield (kg/cow), and harvest time (s/kg milk, using time from entry to AMS to time of exit) were all analysed using ANOVA. Daily yield was calculated for each cow by summing the total production for each cow over the treatment period and dividing this total yield by the number of days in each treatment period (28 d). Harvest time was calculated for each milking before a mean was calculated for each cow. Interactions with each of these parameters and stage of lactation were also analysed using ANOVA.

Means for milk time and dead time were obtained for each cow for each period and analysed for treatment differences using ANOVA.

Table 1. Summary of cow behaviour during teat brushing and cup attachment for the two treatments (Brushed = ~45 s teat brushing prior to cup attachment; NB = no brushing)

	Brushed	NB	*P* value	SED
Number of observations	110	117		
Average number of leg lifts during brushing	1·17			
Average number of leg lifts during cup attachment	2·56	2·89	0·304	0·15
Average number of kicks during brushing	0·07			
Average kicks during cup attachment	0·13	0·12		
% milkings with >0 kicks	7·27	7·69		
% failed milkings (angular transformation)	3·76	5·10	0·285	1·46

Results

Observations of teat brush rollers

Observations were made on a total of 130 milkings during both treatment periods. All cows observed received at least some level of brushing from the rollers but only 67% (87/130) received brushing of all four teats. A total of 88% (114/130) of cows received at least some brushing on three or more teats and 98% (127/130) of cows received at least some brushing on two or more teats. Only 76% (99/130) of cows on the brushing treatment received the full level of brushing intended (~45 s contact time between teats and brushes).

Cow behaviour during teat brushing

Observations of cow behaviour were carried out on a total of 227 milkings over the trial period (110 B and 117 NB). A summary of behaviour during teat brushing is shown in Table 1. Brushing before milking resulted in an average of 1·17 leg lifts during the process of brushing. There was no difference in the number of leg lifts between the two treatment groups during the attachment phase of the milking (B = 2·56, NB = 2·89 leg lifts during cup attachment; $P = 0{\cdot}304$). Only 7% of observed milkings had one or more kicks during the brushing phase of milking. The average number of kicks observed during the cup attachment phase was 0·13 (B) and 0·12 (NB) with a range

Table 2. Summary of milking parameters and ANOVA outcomes for cows in brushing or no brushing (NB) treatment groups

	Brushed	NB	SED	*P* value	SOL int†
Milk Processing Time (min/milking)‡	10·30	9·76	0·16	0·0011	0·529
Cups-on-time (min/milking)§	8·44	9·02	8·2	0·0001	0·413
Milk yield/milking (kg)	12·36	12·22	0·19	0·4760	0·429
Milk yield/d (kg)‖	14·67	14·71	0·18	0·8260	0·592
Harvest time (s/kg milk)	45·62	48·51	0·83	0·0011	0·807

† SOL int = *P* value for ANOVA with stage of lactation interaction
‡ Time from entry to AMS to time of exit
§ Time from attachment of first cup to removal of last cup
‖ Total yield per cow over each treatment period divided by 28 d per treatment period

of 0–5 observed in each treatment group. There was no difference in the proportion of unsuccessful milking attempts (B = 3·76 %, NB = 5·10 %; $P = 0·285$).

Milking parameters

During the data collection period the average milking frequency was 1·2 milkings/cow per day. This equates to an average interval of 20 h between successful milkings and is slightly higher than the targeted milking interval for this study. A summary of the milking performance results is presented in Table 2. Milkings preceeded by brushing averaged 0·54 min longer milk processing time than NB milkings (B = 10·30, NB = 9·76 min/milking; $P < 0·01$). Cups-on-time per milking was reduced when cows were brushed before cups were attached (B = 8·44, NB = 9·02 min/milking; $P < 0·001$). The milk harvest time was 2·9 s/kg milk faster ($P < 0·01$) for the milkings preceeded by brushing. There was no difference in the milk yield per milking (kg) for the two treatment groups or the yield/d. There were no significant interactions between stage of lactation and milk processing time, cups-on-time, milk yield/milking or milk yield/d.

Quarter parameters

Results of the milking time and dead time analyses are presented in Table 3. Cows in the brushed treatment group had a significantly shorter milking time for the left front quarter ($P < 0·05$) but brushing had no effect on mean milking time for other quarters ($P > 0·05$). Dead time was significantly shorter for cows in the brushed group for the left rear, right rear and right front quarters ($P < 0·05$) and mean dead time for all quarters was significantly shorter for brushed cows ($P < 0·001$).

Discussion

When teats were brushed prior to milking, overall milk processing time was longer but cups-on-times shorter than when brushing was not used. Despite the benefits of pre-milking stimulation (shorter cups on time) afforded by the brushing treatment, the overall milk harvesting rate was lower as a result. This result has implications for the efficient utilization of AMS in extensive grazing systems.

Table 3. Summary of milking time (seconds/milking) and dead time (seconds/milking) and ANOVA outcomes for cows in brushed or no brushing (NB) treatment groups (LR, left rear; RR, right rear; RF, right front; LF, left front quarter)

	Brushed	NB	SED	*P* value
Milk time LR	382·6	372·5	7·31	0·173
Milk time RR	349·0	352·3	5·71	0·566
Milk time RF	286·8	279·2	6·65	0·257
Milk time LF	247·9	258·3	4·85	0·037
Mean milk time	316·6	315·6	4·65	0·830
Dead time LR	32·1	44·6	2·51	0·0000
Dead time RR	34·9	44·1	4·06	0·027
Dead time RF	37·9	44·6	2·88	0·024
Dead time LF	34·3	38·0	2·33	0·119
Mean dead time	34·8	42·8	1·61	0·0000

The results showed that although 100 % of cows observed in the brushing treatment did in fact receive at least some level of brushing, only 76 % of cows intended for preparation received the full level of brushing. The importance of full stimulation as opposed to a variable level of pre-stimulation in order to achieve the maximum lactation yield advantages have been shown by Merrill et al. (1987) and Rasmussen et al. (1990). In the present study, the effects of the brushing treatment on cups-on time indicates that the level of stimulation achieved was sufficient to have a biological effect on milk flow characteristics. However, the benefits of pre-milking stimulation may have been greater had full brushing been achieved on all occasions. These results suggest that technological advances would improve the proportion of teats successfully brushed prior to cup attachment.

Overall it appears that pre-milking brushing had little impact on cow behaviour in the milking crate. All cows in the study were familiarized with the brushing process prior to the treatment period so it was not a new experience to them. It had been hypothesized that the teat brushing might assist cup attachment rates as cows might be better positioned in the milking crate following brushing. The results showed that there was no difference in proportion of unsuccessful milkings between the brushed and not-brushed treatments. The average number of leg lifts during

https://doi.org/10.1017/S002202990500155X Published online by Cambridge University Press

cup attachment in this trial (2·7) could be considered to be relatively low compared with reports from Prescott et al. (1998) that cows given food in the AMS crate averaged 6·7 shuffling episodes per milking during the attachment phase. In contrast, the average number of kicks during the attachment phase were higher than that reported by Prescott et al. (1998) where 0·1% of milkings resulted in kicking during the attachment phase, compared with 7% observed in the present experiment.

The actual time taken by brushing was 1·12 min/milking, which is within the reported 1–2 min (non-milking crate time calculated as crate time minus cups-on-time) between the start of teat stimulation and the onset of milk ejection (Bruckmaier et al. 1994). The cups-on-time, milk harvest time and quarter dead time data all indicated that pre-milking brushing resulted in cows having a quicker milk let-down in relation to cup attachment and higher milk flow rate, consistent with the known effects of pre-stimulation (Svennersten-Sjaunja et al. 2004). Tactile stimulation of the teats evokes the milk ejection reflex through the release of the pituitary hormone oxytocin which in turn causes contraction of the myoepithelial cells and the expelling of milk from the alveolar to cisternal compartment of the udder (see review by Svennersten-Sjaunja et al. 2004). The net effect of pre-stimulation is a quicker milk flow rate and therefore shorter machine-on time as milk is already flowing into the cisternal cavities when milking cups are attached. Even though pre-milking brushing resulted in 0·58 min/milking shorter cups-on-time, it resulted in an average increase in overall milk processing time of 0·54 min/milking (32 s/milking). The brushing process had no effect on milk yield/milking, daily milk yield/cow, or proportion of unsuccessful milking attempts. The net result was a cost of 0·54 min/milking with no milk yield advantages. This equates to an additional 5–6 milkings for every 100 milkings per machine compared with the brushing strategy, which in a system aiming for a high cow to AMS ratio will influence potential milk output per AMS.

Depending upon level of tactile stimulation achieved by the brushes and speed of cup attachment, there are likely to be variable intervals between brushing and cup attachment for each teat. The present results show that the difference between brushed and not-brushed teats for dead time is variable and dependent on teat position. During a brushing treatment the rear teats were brushed first followed by the front teats. The sequence of cup attachment is similar in that the rear cups are attached first followed by the front cups. Furthermore, the rear teat that generally has the longest cups-on time for a particular cow will be attached first. The same rule applies to the front teats. The tactile stimulation created in cup attachment may be sufficient stimulation so that no significant delay in milk let-down occurs at the left front quarter.

Pre-milking brushing may have impacts on cows in the AMS as a result of a slower throughput. Depending on cow traffic flows, the longer each cow spends in the AMS crate, the longer subsequent cows have to spend waiting on the concrete yard or cow laneways to the dairy, resulting in reduced time on pasture and possibly negatively influencing their motivation to return to the dairy. This is particularly relevant to forced cow traffic systems where cows must pass through the AMS to access feeding areas or systems where cows are pre-selected for milking as they cannot simply return to the resting/feeding area if the AMS is occupied. In grazing systems such as on this research farm, cows walk considerable distances to the AMS (up to 900 m) and minimal (if any) feed is available at the dairy. It is important for cow flow and to encourage return visits to the AMS that minimal time is spent in the waiting yard.

Whilst it is not common practice to wash cows' teats prior to cup attachment in New Zealand dairies, the person attaching the cups is required to wash individual udders if they appear to be visually dirty. In an AMS, cows are milked without human assistance and the technology currently available does not have the ability to wash only those cows that visually appear dirty. Although not specifically studied in the present experiment, milk quality may be compromised through the lack of ability to selectively clean dirty teats particularly during times of the year when environmental conditions predispose to hygiene defects. Whilst it was not measured in this study, there is potential for a negative effect on teat condition with the increased cups-on-time associated with no teat brushing. One positive aspect of the AMS washing process is that the brushes are disinfected after brushing each cow, so those teats contacted by the brushes are sanitized prior to cup attachment.

Routine udder preparation prior to milking is currently not carried out on New Zealand dairy farms. A series of studies by Phillips through the 1950s to 1980s showed that the relative effect of pre-milking stimulation on long-term milk production had decreased for New Zealand cows, probably as a result of breeding and selection. While the current study showed no effect of pre-stimulation on short-term milk yield, brushing prior to cup attachment significantly reduced milking duration owing to higher milk flow rates. The New Zealand cow is likely to have changed since the work of Phillips in the 1980s possibly as a result of the increased use of US Holstein genes. Currently the proportion of US Holstein genes in the national New Zealand herd is estimated to be around 38% (Harris & Kolver, 2001). Differences in milking speed have been reported for North American Holsteins and New Zealand Friesians (Kolver et al. 2000). Effects of pre-milking stimulation on milk processing time deserve further investigation to determine the impact of increased US Holstein genes on milking characteristics of current New Zealand cows.

Cows with well-filled udders require a shorter period of stimulation to elicit a milk let-down response than cows with less-filled udders (Dzidic et al. 2004). With the long milking interval targeted and achieved under the conditions of this trial it is possible that a shorter brushing time may be sufficient to reduce cups-on-time without increasing the total milk processing time. This aspect of pre-milking udder preparation requires further research specific to the New Zealand situation.

In the present study, the cows were in mid–late lactation. The time cost of the brushing in the AMS system was larger than the time saving in milking duration and no production effects were evident. The outcome might differ in peak or early lactation as the requirement for stimulation is typically reduced owing partly to udder fill and partly to physiological response (Svennersten-Sjaunja et al. 2004). Therefore the differences in cups-on-time due to brushing reported here would be expected to reduce.

Effects of pre-milking stimulation on milk yield vary in the short term *v.* long term (Svennersten-Sjaunja et al. 2004). In the short term, stimulation has its largest effect on milk flow, which can be bimodal without pre-stimulation, with little effect on milk yield. In the longer term, there is a tendency for enhanced lactation yield. It is likely that this effect is resultant of more efficient udder emptying. Clearly the longer term effects of the presence or absence of pre-milking brushing are not known from this initial study and deserve further attention in order to understand fully the implications of pre-milking udder preparation in AMS within New Zealand's extensive grazing dairying system, having regard to the breeding history of the New Zealand cow population.

The authors gratefully acknowledge the contribution of Steve Davie for animal management and Barbara Dow for assistance with data analyses. Thanks to all Dexcel staff who assisted with the observation work. The authors acknowledge the support of joint venture partner Sensortec Ltd (New Zealand) for contributing the Fullwood Merlin Automatic Milking Systems and technical support to the research programme. We also acknowledge the input and support of the Agricultural Marketing and Research Development Trust farmer group throughout this project. This research was part of a research program funded by Dairy Insight (Contract No. 10080) and the New Zealand Foundation for Research, Science and Technology (Contract No. DRCX0201).

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