



Health of dairy cows milked by an automatic milking system

Effects of milking interval on teat condition and milking performance with whole-udder take off

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Information

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Effects of milking interval on teat condition and milking performance

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Abstract

As part of the EU project on Automatic Milking (AM) a study was carried out in the Netherlands, United Kingdom and Denmark on “Health of dairy cows milked by an automatic milking system”. The major part of this project was a study of 15 farms in each country. A separate experiment was conducted to determine the effects of milking intervals on the short-term effects of teat condition. Milking with shorter intervals leaves less time for teat tissue to recover and may lead to incomplete recovery of teats. This could lead to an accumulation of teat trauma. It suggests that a measurable risk may occur when using an AM system, if milking intervals are short.

An experiment was undertaken on the impact on teat condition when milking with short milking intervals as can be found with automatic milking. A Latin-square designed experiment in a conventional milking parlour used 12 cows which were allocated randomly for a period of 4 days, being milked every 4, 8, or 12 hours. The cows were housed in a free-stall barn and milked on one side of a 2 x 5 side-open milking parlour with whole udder cluster take off. After two days habituation, milk flow profiles were collected on the third day. At morning and evening milking on the fourth day, the two right teats were examined with ultrasound just before and just after milking to measure differences in teat dimensions. Milk samples were taken to determine milk composition.

Statistical analyses using random regression showed that milk yield increased 16% per day when milking frequency was greater than two times a day. First parity cows produced significantly less milk than older cows when milked twice a day. The overall increase in milk yield per day when cows were milked more than twice a day was only found for first parity cows. Milking six times a day, with whole udder take-off, doubled the machine-on time. The efficiency of milk harvesting decreased with increasing milking frequency.

Shorter milking intervals resulted in less increase in teat wall thickness, less reduction in teat cistern width and less shortening in teat canal length in response to milking. However, the teats milked following short intervals had thicker teat walls, narrower teat cisterns and longer teat canals **before** milking. These differences between the treatments in teat dimensions disappeared **after** milking. This indicates either that short milking intervals are insufficient to allow recovery of teat tissue between milkings or are a result of less filling of the teat cistern with milk. Furthermore, in this experiment whole udder take-off was practised, most of the AM systems use quarter take off. This may reduce the effects on teat condition because of a shorter low flow period for individual quarters at the end of milking. In this experiment front teats had a larger increase in overall teat width because of milking than rear teats. The low flow period in front quarters will be longer than in rear quarters with whole udder take-off. The cause and effect of changes in teat dimensions after milking still require further investigation.

Milk composition, milk fat, protein, lactose and cell count, at different milking intervals was not different.

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1 Introduction

Automatic milking offers the possibility for dairy cows to select their own routine. Cows can visit an automatic milking system more often than the twice a day that is usually applied in the traditional milking parlour. Efficient use of commercial automatic milking (AM) systems should normally mean that milking intervals do not become too short and that milking frequency and interval can be managed to avoid any adverse patho-physiological effects on teats. However, neither the optimum milking interval nor milking conditions for AM systems in terms of teat condition are known.

Determining any changes to teat condition in response to AM is part of the project *Implication of the introduction of automatic milking on dairy farm*. Work package 8 *Health of dairy cows milked by an automatic milking system* seeks to study the health of a number of dairy herds over the transition from conventional to automated milking. One objective is to identify and specify the possible effects of automatic milking on teat condition and thus udder health.

An initial review of the literature on conventional milking and appraisal of AM systems suggested that automated milking could be made to achieve good teat condition but that not all hazards may be known and that the level of risks may vary with the operating conditions of the milking system and the management of the herd (Neijenhuis and Hillerton, 2002). The hazards of automatic milking on teat condition will be related mostly to the milking conditions and the frequency of milking. The risk of milking with one or a few AM units as opposed to a multi point milking parlour is probably small, except when there is use of one liner per teat for an extended period and that liner is inadequate (Hillerton et al., 2003). The effects of machine milking on teat condition can be quantified after short-, medium or long periods of lactation (Hillerton et al., 2000). Teat-end swelling just after milking is a short-term teat condition (Mein et al., 2001). Teat swelling can be measured using ultrasound (Spencer et al., 1997; Neijenhuis et al., 2001; Gleeson et al., 2002). Recovery from teat end swelling induced in conventional milking may take 6 to 8 hours (Neijenhuis et al., 2001). Milking with shorter intervals leaves less time for teat tissue to recover and may lead to incomplete recovery of teats (Rasmussen et al, 2001; Hamann and Østerås, 1994). This could lead to an accumulation of physiological dysfunction of the teat. It suggests that a measurable risk may occur when using an AM system and if milking intervals are short. Studies on one farm with an AM system showed that there was a large variation in milking interval (de Koning & Ouweltjes, 2000). No research is known in which multiple milkings with very short intervals are described but with a median milking interval of 8 h, 9.7% and 0.5% of the milkings had a preceding milking interval shorter than 6 and 4 h respectively (Hogeveen et al., 2001), so some risk may exist. However, Berglund et al., (2002) found teats less discoloured after milking with AM, although teat skin was drier. De Vliegher et al. (2003) found, using a good quality teat conditioning disinfectant, that neither teat skin nor orifice condition were significantly affected when changing from conventional to automatic milking.

The hypothesis to be tested is that the effects of repeated milkings with too short recovery time for teat condition can be measured using ultrasound. The aim of this experiment is to determine the effects of milking intervals of 4, 8 and 12 hours on the short-term effects of teat condition measured under controlled conditions to help assess risks from short milking intervals or higher milking frequencies.

2 Materials and methods

2.1 Cows

Twelve cows were selected from the dairy herd at the Institute for Applied Research on the basis of milk yield greater than 25 kg per day and no clinical mastitis detected during the current lactation. The cows were an average 144 (range 37 to 178) days in milk at the start of the experiment. Four of the selected cows were in first, two in second, three in third and three in the fourth or higher parity. The 305-days milk yield was predicted to average 9900 kg (range 7694 to 14422 kg). Cell count averaged 156.000 cells/ml (range 18.000 to 991.000 cells/ml, with only one cow more than 200.000 cells/ml).

2.2 Milking parlour

The experiment took place in the experimental milking parlour of the Waiboerhoeve, The Netherlands. The cows were housed in a free stall barn and milked at one side in a 2 x 5 side-open milking parlour. During the experimental periods, all cows passed the milking parlour every 4 hours and were milked according to their allocated treatment.

When cows were recognised for milking, the milking parameters were set according to the treatment in the experimental design. A milking machine (Gascoigne Melotte, Emmeloord, The Netherlands) with 45 kPa milking vacuum was used with a Gascoigne Melotte cluster (liner type D381988). All liners were mounted in the teatcup shells at the same angle of collapse to facilitate measurement of teat tissue response. A pulsation rate of 60 pulses/min and a pulsation ratio of 65:35 were used.

Pre-milking treatment consisted of cleaning teats with a paper towel (10 seconds), followed immediately by attachment of the cluster. Cluster removal was triggered automatically at an average milk flow rate of less than 200 g/min for 15 sec.

Milk yield and milk flow profiles were recorded using glass jars mounted on weigh cells. Hardware and software specially designed for this experimental milking parlour allows milk yield and milk flow to be recorded every second (+/- 25 grammes).

2.3 Experimental design

A Latin-square design of three experimental periods of 4 days were used separated by 3 day breaks when the cows were milked twice-daily with intervals of 10 and 14 hours. Cows were allocated at random to treatment of being milked every four, eight or twelve hours. The 4-day treatment period consisted of two days as a habituation period, then on day three milk-flow profiles were measured and on day four the reactions of the teats were measured.

2.4 Measurements

2.4.1 Milk flow profile parameters

The milk flow profiles allowed calculation of total milk yield (kg), machine-on time, maximum milk flow rate and average milk flow rate. Machine-on time and milk yield were also calculated on a daily basis.

The milk flow profile can be divided into four phases (adapted from Goff, 1992) (Figure 1).

Phase 1: low milk flow period at the beginning of milking allowing calculation of

%Phase1 the percentage of machine-on time during phase 1

During the first phase of the milk flow profile, a dip in milk flow may occur, the so-called bimodality. Before the dip occurs, milk flow should be more than 0.3 kg/min within 40 seconds after attachment. For bimodality the following were calculated:

Sbmod: starting time (s) after cluster attachment when bimodality appears

Ebmod: time (s) after cluster attachment when bimodality ends (milkflow is 0.3 kg/min higher than the minimum during bimodality)

Lbmod: length (s) of bimodality (ebmod - sbmod)

Nbmod: maximum flow rate before bimodality (kg/min)

Obmod: time (s) when milk flow returned to maximum (Nbmod) before bimodality

Mbmod: lowest milk flow during bimodality (kg/min)

Phase 2 : plateau period with steady milk flow starting when milk flow was more than 0.8 kg/min and the increase in flow is less than 0.28 kg in 20 sec (equivalent to 0.8 kg/min) and ends when the decrease in milk flow is over 0.27 kg in 20 sec

%Phase2 the percentage of machine-on time during phase 2

Calculations were:

Splat: time (s) after cluster attachment when phase 2 started

Eplat: time (s) when phase 2 ended

Nplat: average milk flow of plateau (kg/min)

effic: efficiency score when milk flow exceeded 1 kg/min, compared to total machine-on time (%)

Phase 3: decreasing milk flow period ending when milk flow drops to 420 g/min

%Phase3 the percentage of machine-on time during phase 3

Calculations were:

Uplat: time when milk flow is decreased to less than 420 g/min (s)

Phase 4: after milk flow phase until the cluster is removed.

%Phase4 the percentage of machine-on time during phase 4

The milk yield half way through the plateau phase was calculated. The efficiency of milk flow was calculated as the percentage of the total milk yield that is produced during the plateau phase.

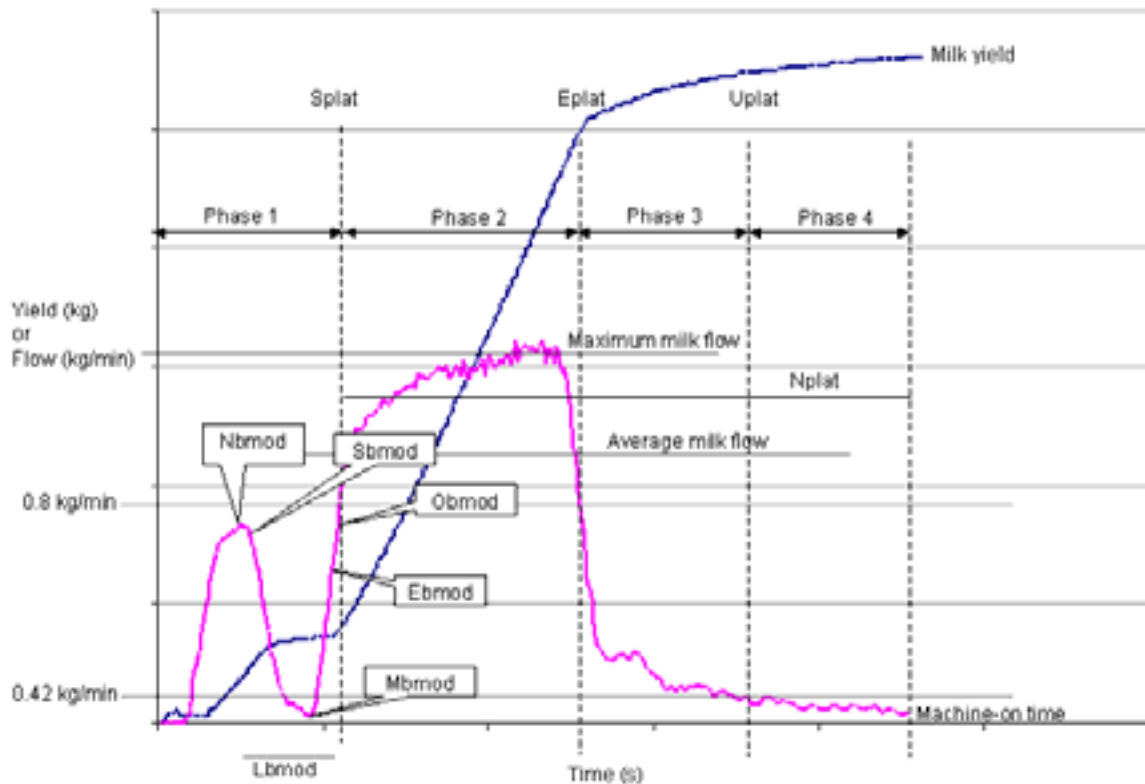


Figure 1: Typical milk flow profile with bimodality present.

2.4.2 Teat dimension

Ultrasonographic scans of teats were carried out with a 200 VET scanner with a linear array 7.5 MHz probe (Pie Medical, Maastricht, The Netherlands). During scanning, the teat was immersed in a latex bag of water (35°C) and the probe with contact jelly was held against this bag. The position of the probe was lateral to the teat and on the flat collapsing side of the liner.

Ultrasound measurements of teats were made between pre-treatment and unit attachment and directly after unit take-off. The real-time scanning was shown at the scanning device and stored. Image transfer was carried out using the OdtCom communication software and measurements of the teat scans was made by one person, using the Eview software (version 1.00, Pie Medical Equipment B.V., Maastricht, The Netherlands, 1996).

Measurements were (Figure 2):

- Teat canal length
- Overall teat width at the proximal end of the teat canal

Teat wall thickness 1 cm proximally from the end of the teat canal.
 Teat-cistern width 1 cm proximally from the end of the teat canal.

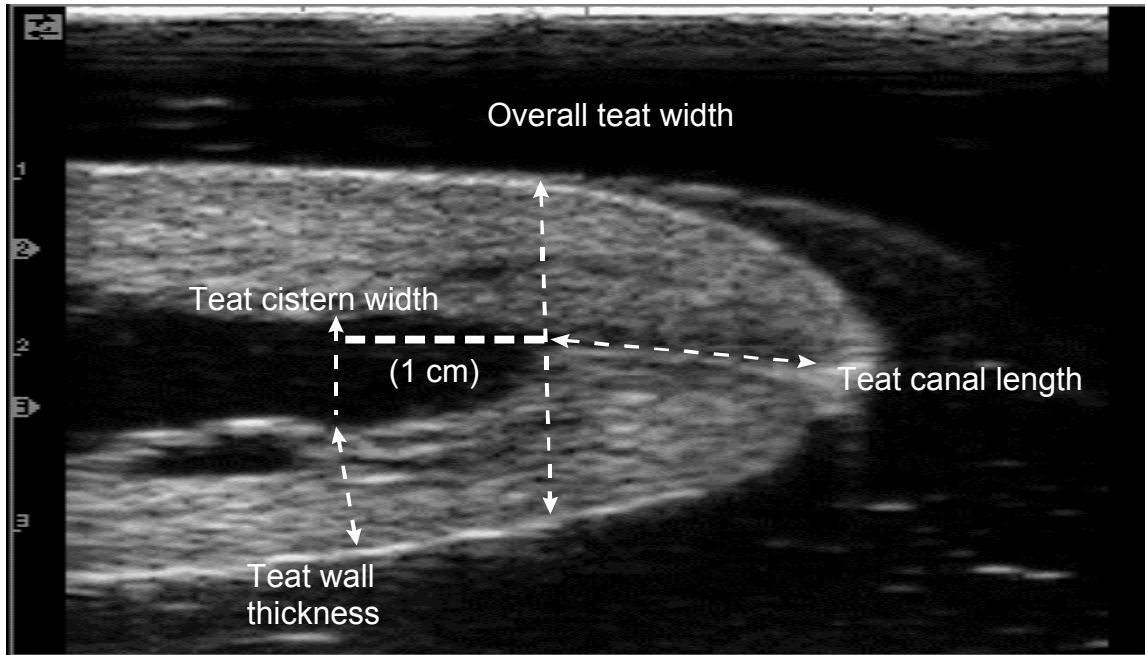


Figure 2: Measurements from an ultrasonic scan of a teat.

2.4.3 Milk composition

On day four of each experimental period, milk samples from one morning and one evening milking were analysed for percentage of milk fat, protein, lactose and cell count.

2.5 Statistical analyses

Random regression models were fitted using REML (Genstat – Sixth edition, Lawes Agricultural Trust).

The model fitted for milk flow profile parameters and milk composition was:

$$Y_{ijklmn} = \mu + (C(D))_{ij} + \text{Treatment}_m * \text{Par}_n + e_{ijklmn}$$

where:

- Y_{ijklmn} = milk flow parameters,
- μ = overall mean,
- $(C(D))_{ij}$ = random effect representing nested time of milking D (i=morning or evening milking) within cow C (j = 1...12)
- Treatment_m = fixed effect of treatment (m=milking interval 4, 8 or 12 hours),
- PAR_n = fixed effect of parity (n=first or older parity), and
- e_{ijklmn} = residual effect.

The model fitted for teat dimensions was:

$$Y_{ijklmn} = \mu + ((C(T))*(P(D)))_{ijkl} + \text{Treatment}_m + \text{Teat}_n + e_{ijklmn}$$

where:

Y_{ijklmn} =	teat-tissue measurements before and after milking or the difference between before and after milking as a percentage of before milking (overall teat width, teat wall thickness, teat canal length and teat-cistern width)
μ =	overall mean,
$((C(T))*(P(D)))_{ijkl}$ =	random effect representing nested teat T (k=right rear or right front teat) within cow C (j = 1...12) crossed by nested time of milking D (i=morning or evening milking) within experimental period P (l=1,2,3),
Treatment_m =	fixed effect of treatment (m=milking interval 4, 8 or 12 hours),
Teat_n =	fixed effect of teat position (n=rear or front teat), and
e_{ijklmn} =	residual effect.

Significant effects were assumed when the P-value for main effects was <0.001 and for interaction terms < 0.05.

3 Results

3.1 Milk flow profiles

The cows yielded an average 32 kg of milk during day 3 of all periods. With milking intervals of 4 or 8 hours the milk yield increased by nearly 4 kg per day (16%) compared to intervals of 12 hours (Table 1). Milking time per day was 22 minutes on average. When milked every 4 hours, machine-on time more than doubled compared to milking twice a day. The differences in machine-on time occurred because of a lower maximum and average milk flow.

Table 1. Effect of interval between milkings on milk flow profiles.

Milking interval (h)	Milk yield per milking (kg)	Milk yield per day (kg)	Machine-on time per milking (min)	Machine-on time per day (min)	Maximum milk flow (kg/min)	Average milk flow (kg/min)
4	5.6 ^a	33.8 ^a	5.1 ^a	30.9 ^a	2.7 ^a	1.2 ^a
8	11.3 ^b	33.9 ^a	6.2 ^b	18.6 ^b	3.7 ^b	1.9 ^b
12	14.7 ^c	29.3 ^b	6.9 ^c	13.7 ^c	3.7 ^b	2.2 ^c
sed	0.5	1.7	0.3	1.1	0.2	0.1

Within a column means with different superscripts differ significantly ($P < 0.001$)

The efficiency of milking decreased when milking more frequently (Table 2). The lower efficiency was demonstrated by distribution of yield and machine-on time between the phases (Tables 3 and 4). The time between entering the milking parlour and cluster attachment (waiting time) did not differ between treatments.

Table 2. Effect of interval between milkings on milk flow profiles.

Milking interval (h)	Efficiency (% time milk flow > 1 kg/min)	Waiting time before cluster attachment (sec)
4	44.1 ^a	28
8	66.2 ^b	24
12	78.9 ^c	27
sed	3.2	3

Within a column means with different superscripts differ significantly ($P < 0.001$)

The milk yield harvested and the time spent within each phase of the milk flow profile (Tables 3 and 4) show that, with the short milking intervals, proportionally more milk was harvested in phase 4 and proportionally more time was spent in phases 1 and 4.

Table 3. Effect of interval between milkings on distribution of milk yield and the proportion of total milk between phases of the milk flow profiles.

Milking interval (h)	Milk yield (kg) per phase				Proportion (%) of milk per phase			
	1	2	3	4	1	2	3	4
4	0.9 ^a	2.7 ^a	1.6 ^a	0.5 ^a	15.4	46.5	26.9 ^a	11.1 ^a
8	1.8 ^b	5.3 ^b	3.9 ^b	0.4 ^{ab}	16.8	45.5	34.3 ^{ab}	3.4 ^b
12	2.1 ^c	7.4 ^c	5.1 ^c	0.2 ^b	14.0	49.6	35.4 ^b	1.0 ^b
Sed	0.2	0.5	0.4	0.2	1.6	3.8	3.8	4.5

Within a column means with different superscripts differ significantly (P<0.001)

Table 4. Effect of interval between milkings on machine-on time (% of total machine-on time) within the phases of milk flow.

Milking interval (h)	%Phase 1	%Phase 2	%Phase 3	%Phase 4
4	32 ^a	23 ^a	27 ^a	18 ^a
8	24 ^b	27 ^a	37 ^{ab}	12 ^b
12	20 ^c	34 ^b	40 ^b	6 ^c
sed	2	3	3	2

Within a column means with different superscripts differ significantly (P<0.001)

Bimodality of milk flow was seen in 25%, 79% and 71% respectively of the milk flow profiles with milking intervals of 4 hours, 8 and 12 hours. Within these bimodal flow curves, bimodality was seen approximately 26 seconds after attachment of the cluster (Sbmod) for all treatments and lasted longer when milking every 4 hours (Lbmod) (Table 5). The maximum milk flow before the bimodality was lower (Nbmod), and the milk flow during the bimodality (Mbmod) was lower with shorter milking intervals.

Table 5. Effect of interval between milkings on bimodality characterization of the milk flow profiles with bimodality (only bimodal flow curves).

Milking interval (h)	Sbmod (s)	Lbmod (s)	Nbmod (kg/min)	Mbmod (kg/min)
4	24	41 ^a	0.3 ^a	0.1 ^a
8	27	32 ^b	1.1 ^b	0.5 ^b
12	28	34 ^b	1.6 ^c	1.0 ^c
Sed	3.3	3.6	0.2	0.2

Within a column means with different superscripts differ significantly (P<0.001)

The plateau flow phase (Phase 2) started later (Splat), ended earlier (Eplat), and was thus shorter with shorter milking intervals (Table 6) although the milk yield in phase 2 was around 45% compared to the total milk yield and did not differ between treatments (Table 3). The

average milk flow in phase 2 (Nplat) was lower with shorter milking intervals. The time when milk flow was decreased to less than 420 g/min (Uplat) was reached earlier with shorter milking intervals.

Table 6. Effect of interval between milkings on phase 2 of the milk flow profiles on day three of the experimental periods.

Milking interval (h)	Splat (s)	Eplat (s)	Nplat (kg/min)	Uplat (s)
4	92 ^b	157 ^a	2.5 ^a	237 ^a
8	83 ^b	185 ^b	3.5 ^b	326 ^b
12	75 ^c	211 ^b	3.5 ^b	385 ^c
sed	6	13	0.2	25

Within a column means with different superscripts differ significantly (P<0.001)

3.1.1 Parity effect on milk flow profile

An effect of parity was found on milk yield per milking, first parity cows produced significantly less milk when milked after an interval of 12 hours compared to older parity cows (Table 7). Milk yield per day was increased only for first parity cows when increasing the milking interval from 12 to 4 or 8 hours. The increase in milk yield per day was not found for older parity cows. First parity cows produced significant less milk per day than older cows when milked twice a day.

The maximum milk flow increased for older parity cows when milking interval was decreased from 4 to 8 to 12 hours (Table 7). This increase in maximum flow was only found from 4 compared to 8 or 12 hours for first parity cows. The start of phase 2 or plateau phase (Splat) was earlier and the decrease in flow (Uplat) was reached earlier for first parity cows compared with older cows. The average milk flow in phase 2 (Nplat) was higher for first parity when milked with intervals of 4 or 8 hours. No difference was found between first and older parity cows in the total length of phase 2.

The machine-on time per milking and per day was, on average, shorter for first parity cows than older cows. On daily basis, the increase in machine-on time was less (min/day) for first parity cows than older cows when the milking interval was shorter. This difference was not apparent when comparing the increase in percentages within parity. The machine-on time per day increased 27% and 40% when decreasing the milking interval from 12 to 8 and 8 to 4 hours respectively.

Table 7 Effect of interval between milkings and parity on milk yield per milking.

Milking interval (h)	First parity * kg/milking	Older parity kg/milking	First parity kg/day	Older parity kg/day	First parity Max milk flow	Older parity Max milk flow
4 *	5.3 ^a _a	6.0 ^a _a	31.9 ^a _a	35.7 ^a _a	3.1 ^a _a	2.3 ^a _a
8	10.7 ^b _a	11.9 ^b _a	32.2 ^a _a	35.7 ^a _a	4.0 ^b _a	3.3 ^b _a
12	12.8 ^c _a	16.5 ^c _b	25.5 ^b _a	33.1 ^a _b	3.6 ^b _a	3.8 ^c _a

Within a column for parity means with different superscripts * differ significantly, and between 2 columns for treatment means with different subscripts * differ significantly (P<0.05)

3.2 Teat dimensions

There were 144 ultrasonic scans of the right two teats of the 12 cows made in three periods at a morning and an evening milking.

At the start of each treatment cycle teat wall width just before cluster attachment was on average 7 mm, teat cistern width 9.5 mm, overall teat width 21mm and teat canal length was 12.6 mm. Teat parameters after milking were not significantly different between treatments (Table 8).

Table 8. Effect of interval between milkings on teat parameters after milking:

Milking interval (h)	Teat wall thickness (mm)	Teat cistern width (mm)	Overall teat width (mm)	Teat canal length (mm)
4	8.3	6.5	21.2	13.8
8	8.4	6.5	21.1	13.6
12	8.4	6.2	21.0	13.5
sed	0.2	0.5	0.2	0.3

Within a column means with different superscripts differ significantly ($P < 0.001$)

Shorter intervals between milkings resulted in thicker teat walls, smaller teat cisterns and longer teat canals before the next milking (Table 9).

Table 9. Effect of interval between milkings on teat parameters before milking.

Milking interval (h)	Teat wall thickness (mm)	Teat cistern width (mm)	Overall teat width (mm)	Teat canal length (mm)
4	7.6 ^a	7.6 ^a	21.0	13.1 ^a
8	7.0 ^b	9.7 ^b	21.1	12.7 ^b
12	6.5 ^c	11.1 ^c	21.0	12.0 ^c
sed	0.2	0.5	0.1	0.2

Within a column means with different superscripts differ significantly ($P < 0.001$)

The average increase in teat wall thickness because of milking was 22%, for teat width it was only 0.6%, for teat canal length 10% and the teat cistern width decreased 24%. Shorter intervals between milking resulted in a smaller increase in the changes in dimensions of the teat wall, teat cistern and teat canal (Table 10).

Table 10. Effect of interval between milkings on teat parameters after – before milking as a percentage of the value before milking (%):

Milking interval (h)	Teat wall thickness	Teat cistern width	Overall teat width	Teat canal length
4	10.3 ^a	4.0 ^a	1.2	6.6 ^a
8	23.5 ^b	-31.9 ^b	0.4	8.1 ^a
12	33.3 ^c	-44.7 ^b	0.3	14.2 ^b
sed	5.0	12.4	0.9	2.4

Within a column means with different subscripts differ significantly ($P < 0.001$)

3.2.1 Teat position effect on teat parameters

In the model no significant interaction was found between treatment and teat position although rear teats have larger teat cisterns, and shorter teat canals before and after milking than front teats (Tables 11 & 12).

Table 11. Effect of teat position between milkings on teat parameters after milking:

Milking interval (h)	Teat wall thickness (mm)	Teat cistern width (mm)	Overall teat width (mm)	Teat canal length (mm)
Rear	8.4	7.1 ^a	21.1	13.1 ^a
Front	8.4	5.7 ^b	21.1	14.2 ^b
sed	0.5	0.8	0.1	0.2

Within a column means with different subscripts differ significantly (P<0.001)

Table 12. Effect of teat position between milkings on teat parameters before milking.

Milking interval (h)	Teat wall thickness (mm)	Teat cistern width (mm)	Overall teat width (mm)	Teat canal length (mm)
Rear	6.9	10.4 ^a	21.1	12.1 ^a
Front	7.1	8.6 ^b	20.9	13.0 ^b
sed	0.3	0.6	0.2	0.3

Within a column means with different subscripts differ significantly (P<0.001)

The change in overall teat width in front teats was bigger than in rear teats (Table 13). There were no significant differences found between front and rear teats in teat wall thickness, teat cistern width or teat canal length.

Table 13. Effect of teat position between milkings on teat parameters after – before milking as a percentage of the value before milking (%):

Milking interval (h)	Teat wall thickness	Teat cistern width	Overall teat width	Teat canal length
Rear	24.1	-20.2	-0.05 ^e	9.3
Front	20.6	-28.2	1.3 ^f	10.0
sed	3.6	9.4	0.7	2.4

Within a column means with different subscripts differ significantly (P<0.05)

3.3 Milk composition

There were no differences in milk composition between treatments (Table 14). When one cow with a high cell count was excluded, there were also no significant differences in cell counts with milking interval.

Table 14. Effect of interval between milkings on milk composition on day four of the experimental periods (one high cell count cow was omitted).

Milking interval (h)	Protein (%)	Fat (%)	Lactose (%)	Log cell count
4	3.44	4.19	4.56	3.9
8	3.43	3.93	4.55	3.9
12	3.45	3.87	4.53	3.9
sed	0.03	0.22	0.30	0.1

4 Discussion

Milk yield increased approximately 16 percent when the cows were milked more frequently than twice a day. This is consistent with other reports (Kruip et al, 2002; Hillerton et al, 1990, Bramley et al, 1992). No difference in milk yield between three and six times daily milking was found perhaps because this was only a short trial with each session lasting 4 days. Cows used in this short, three-week experiment yielded around 32 kg/day. Three or six times a day milking seems to inhibit the negative feed back on the secretory cells but the effect takes more than one week to become established (Hillerton et al., 1990). First parity cows produced significant less milk than older cows when milked twice a day. The overall increase in milk yield per day when cows were milked more than twice a day was only found for first parity cows.

Milk composition at different milking intervals was not different. No significant decrease fat content was found with increasing milking interval as reported by Weiß et al. (2002). In this experiment, fat content tended to be higher with shorter milking intervals. An increase in milking frequency did not affect SCC, consistent with studies on milking frequencies of two and three times a day (Weiß et al, 2002; Kruip et al., 2002).

Milk flow profiles differed with milking interval. No increase in bimodality at the beginning of milking was found with shorter milking intervals, but this may be an effect of the restricted definition that milk flow must be at least 0.3 kg/min within the first 40 seconds after attachment before bimodality can occur. It may have been that the rate of milk flow was already low with short milking intervals at the beginning of milking because of little udder fill, and a drop in milk flow could not be detected. Other research showed that single quarter milk flow curves may not be bimodal even if the total milk flow curve is bimodal (Rothenanger et al., 1995). Pre-milking teat stimulation induces ejection of alveolar milk ejection before the start of milking. Thus, bimodal milk flow curves (i.e., interruption of milk flow after removal of the cisternal milk) can be avoided (Bruckmaier & Blum, 1998). Milk ejection will tend to occur fastest in early lactation at a milking interval of 12 h and will be delayed with short milking intervals and in late lactation (Bruckmaier & Hilger, 2001). In this trial pre-milking strategy was not adjusted to the milking interval as can occur with AMS. It appears that milking cows with short milking intervals and/or with lower milk yield should be preceded by better pre-milking stimuli. Milking was less efficient with shorter milking intervals, this was shown by lower milk flow rates, more milk at a low flow of 1 kg/min, and, on a daily basis, longer machine-on times.

The teats were measured in an orientation parallel to the plane of collapse of the liner to allow optimum contact of the probe with a 'flat' surface and because the maximum response to the squeeze by the liner is in this plane. Differences in teat diameters after milking could be overestimated because teats tend to be more or less wedge-shaped because of milking. When measuring parallel to the plane of collapse of the liner, the widest diameters are seen.

During this experiment, cluster take off was initiated on a whole udder milk flow of 200 ml per minute. In robotic milking, teat cup detachment per quarter is usual. When detachment levels are accurate, individual quarter detachment will decrease machine-on time on especially on front quarters and therefore should minimise teat trauma. This experiment reports a worst-case scenario.

It is assumed that teat tissue changes reflect teat-canal penetrability. Some teat tissue changes may be measured with a spring-loaded calliper (Hamann et al., 1996; Hamann and Mein, 1988; Peris et al., 2003) and the thickness reflects the mass of tissue and fluid in the teat. A greatly increased teat thickness after milking has been related with a higher risk of infection (Hamann and Mein, 1996) and a higher incidence of clinical mastitis (Rønningen and Reitan, 1990). Longer low flow periods tend to increase teat thickness and should be avoided (Mein et al., 1973).

Teat wall thickness and teat canal length increase and teat cistern width decreases overall because of milking. Old radiographic studies provided evidence of a rapid increase in the thickness of teat walls, particularly during the low flow rate period of milking (Mein et al., 1973). The same effect has been shown here.

This experiment showed thicker teat walls, narrower teat cisterns and longer teat canals before milking when using shorter milking intervals but the differences disappeared, irrespective of milking interval, during milking. It appears that the milking action distorts the teats to approximately the same amount irrespective of milking interval. However, the difference in pre-milking dimensions suggests that shorter milking intervals do not allow sufficient time for recovery of teat tissue to the size and shape, as found when longer milking intervals are applied.

Rear teats had wider teat cisterns than front teats before and after milking but had shorter teat canals which may correlate with more milk in rear quarters (56%) than in front quarters (44%) (Rothenanger et al., 1995). Overall teat width was increased more for front than for rear teats which may occur because front teats tend to be over-milked longer compared to rear teats. This will be not the case in quarter detachment as in AM.

The data on the teat dimensions are similar to that reported by Neijenhuis et al. (2001) in an experiment to look at recovery time of teats. In the inter-milking interval the teats fill slowly with milk and the teat wall thickness decreases with time. It is possible that the thinning of the teat wall, the widening of the teat cistern and the shortening of the teat canal length are not 'recovery' of teat tissue from milking action but an opposite distortion caused by milk volume, a stretching of the teat.

Hamann and Mein (1990) found that little decrease in teat thickness occurred when teats were drained by cannula milking instead of machine milking. Factors affecting changes in teat dimensions may include the decrease in the intra mammary pressure, changes in the teat smooth muscle tone and changes in the distribution of interstitial fluids in the teat apex.

The cause and effect of changes in teat dimensions after milking require further investigation. It would be useful to compare the teat dimensions of cows with milk yield as a factor in a milking interval experiment to show the optimum undistorted teat dimensions. This should include the effects of stimulating milk let-down or not. It could be useful to compare the teats post milking with the dimensions of teats in the dry period.

Physical dimensions of teat tissues are only one factor, more important may be the dynamic responses of teats. Non traumatised teats respond quickly to stimulation after milking by a significant shrinkage, resulting in a shortening of length up to 3 cm and a widening by up to one cm. None of the published reports to-date make any mention of gross changes in teats when the post milking measurements are taking place.

In an AM system short term teat condition measurements are difficult to make because of poor accessibility to the cow's teats in the milking stalls of most systems and it may be unsafe to attempt to examine teats to the sophistication required for this study. In this experiment the cows had to be housed separately and escorted to the milking system at fixed intervals with manual supervision of attachment. These problems required a properly controlled experiment that would be progressive in our understanding of changes in teat tissue and not require the later filling of gaps in knowledge. Hence the design used was not fully reflective of AM systems.

The changes in teat condition found in this experiment maybe not the same when milking cows with an AM system. Here pre-treatment and cluster attachment was done manually. Pre-treatment consisted of dry wiping the udder for 10 seconds, attachment was then immediate. In AM systems pre-treatment is done either per quarter in a teat cup or on whole udder level with roles of cloths or brushes. After cleaning it may take some time to start milking. The lag-time between the start of pre-treatment of the first quarter and attachment of the teat cup will be longer than in this experiment. Therefore, milk let down may be better in an AM system. Bruckmaier et al. (2001) and Macuhova et al. (2003) showed that the use of rolling towels and rotating brushes are a sufficient stimulus for induction of oxytocin release and milk ejection. Dzidic et al. (2003) recommends a minimum stimulation of 64 seconds (four cleaning cycles with brushes) for cows with low udder filling. In this experiment detachment was at cluster level whilst in most AM systems quarter attachment and detachment takes place. Quarter detachment will prevent over-milking especially of front quarters.

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