



Health of dairy cows milked by an automatic milking system

Review of potential effects of automatic milking conditions on the teat

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Health of dairy cows milked by an automatic milking system

Review of potential effects of automatic milking conditions on the teat

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Abstract

Switching from a milking parlour to an automated milking (AM) system may affect the milking performance of the cows, the teat tissues and quality of the milk. Cows are milked voluntarily within an automatic milking system and therefore the milking interval will change from fixed to less even intervals and preferable increase in frequency.

In AM systems pre-milking stimuli should be sufficient for milk ejection. Optimising milking conditions can control milk flow rate and truly separate quarter milking will ensure prompt teat cup removal at the end of milk flow from any one teat. These conditions will minimise any potential for over milking, the factor most likely to impair teat condition. Control of milking conditions in a low-level system, all AM systems are effectively low-level, will also contribute to minimising any machine-milking induced deterioration in teat condition. Cows milked in an AM system will be kept in a more uniform environment, there should be less variation in milking conditions and usually in living space, and control of that environment can be expected to improve husbandry and aid teat management. It may be necessary to improve the spraying, the usual means application, of teat disinfection.

Effective use of existing commercial AM systems should normally mean that milking intervals will not become too short and that milking frequency and interval can be managed to avoid chronic effects on teats. However, the optimum management conditions for the AM systems, the milking conditions or type of liner that should be used are not yet known. Appropriate tools are available to allow the impact of these and any other variables introduced into AM systems to be assessed for their effects on teat condition in the short and longer-term. Priorities for study include these problems and ensuring that the transition from conventional to automated milking does not impair teat condition.

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1. Introduction

Many different milking systems are used for dairy cows. They differ significantly in their physical and engineering design and operation, and in the responses of the cows. Broadly, automated milking systems (AM system) are less variable but the transition from parlour milking to an AM system may involve significant changes both in the system and the associated management of milking. Switching from a milking parlour to an AM system may affect the milking performance of the cows, the teat tissues and quality of the milk. All can be closely associated.

In conventional milking the loads and loading regimens on the teat may affect the teat tissue, cow behaviour and udder disease. The teat is the only direct point of contact between the milking system and the cow. Teats are affected by all forms of milking; calf suckling, hand milking and machine milking all cause changes in teat tissue but usually only of a transitory nature. Even apparently good milking causes physiological changes in the teat, but it is pathological changes that are important. These are changes that remain for a significant part of the inter-milking interval or that transcend milking intervals. Also, in conventional milking the large variety of systems that have evolved may mean that any of a wide range of levels and durations of forces may be applied to the teats.

Changes in husbandry including milking frequency, may affect yield, teat condition, the likelihood of intra mammary disease and hence milk quality. AM systems are relatively new and, to date, they use many fewer types of milking conditions, usually using the 'better' methods developed for conventional milking e.g. all are so-called low-level systems using a milking vacuum of 44 kPa or less. This compares with the range of 40-48 kPa found in other milking systems according to their design.

Cows are usually milked voluntarily within an automatic milking system and therefore the milking interval will change from fixed to less even intervals and preferably increase in frequency. Cluster milking will change to milking each quarter separately and so that any one teat cup is independent of the others. Little is known, as yet, of the responses of cows and teats to AM systems or of the effects of the transition from conventional milking to automated milking. A review of the literature will help to identify potential hazards that may be quantified, and any potential benefits, for further study.

It is necessary to determine if there will be more, fewer or different changes to teats when cows are milking in an AM system. If any changes are determined then the implications of the changes, whether they are manageable, welfare friendly and safe, become important.

2. Role of teats

The teat canal is the primary barrier to invasion of bacterial pathogens into the udder. The sphincter muscle surrounding the teat duct should be fully contracted between milkings to close the teat duct properly and impede bacterial intrusion from the teat opening into the interior of the gland. A teat end in good condition is an important resistance factor to bacterial invasion and subsequent colonisation that leads to intra mammary infection. Changes in teat tissue induced by machine milking, especially impairing the integrity of the teat canal or damaging other structures, may contribute to penetration of bacteria into the udder. Trauma to the lining of the teat sinus may provide an environment favouring bacterial colonisation or multiplication. Local pain may lead to neurohormonal responses that suppress immune function and increase the likelihood of disease.

The duct of the teat canal is lined with keratin. The mature keratin occludes the closed canal and acts as a physical barrier to bacterial invasion. The keratin also has some anti-bacterial properties (Hibbitt et al., 1969). The ability of bacteria to invade through the duct varies with the type of pathogen. Contagious pathogens first colonise the duct and grow there to produce a large challenge. An essential mechanism of limiting this growth is the desquamation of mature keratin largely by the speed or changing speed of milk flow that removes keratin and adhering bacteria. This requires sufficient speed and duration of milk flow. It is not known if a high milking frequency results in a lower milk flow rate, this will also be influenced by stimulation and milking conditions. If milk flow rate is lower in more frequently milked cows using AM systems then this could limit the removal of colonising bacteria. Bacteria of environmental origin are most likely to pass directly through the duct when it is not completely closed (Lacy-Hulbert & Hillerton, 1995). Any changes of duct closure from excessive exposure to milking, possibly subsequent fatigue of the teat sphincter muscles by too frequent milking, may increase the likelihood of such bacteria invading. The presence of bacteria likely to invade or having colonised the teat orifice is largely controlled by the quality of teat disinfection after milking.

It is likely that more frequent milking will result in a shorter milking time for each individual milking. If good milking performance, from proper milk let-down to prompt teat cup removal at the end of milk flow, is achieved, then any fatigue of the teat may be less, so minimising direct bacterial passage into the mammary gland.

Hillerton (1991) showed experimentally that four times daily milking with good milking conditions resulted in fewer infections by colonising bacteria in comparison to twice daily milking. This also suggests that regeneration of teat duct keratin is sufficient. Nothing appears to be known about the effects of more frequent milking on directly invading bacteria so it is important to determine if milking with an AM system tends to leave more teat ducts open, or for a longer time, than conventional milking.

The mechanical forces during machine milking result in changes in teat end tissue. It is these changes that must be optimal to minimise changes in teats. Vacuum helps to open the teat canal and aid milk flow but also draws blood and lymph to the teat end. The collapsing liner may exert a mechanical force on the teat end, contributing to the teat canal closure and transport of blood and lymph back to the udder. The magnitude of the force depends on milking and pulsation vacuum, pulsation, liner type, teat shape and teat size. Any changes in teats when using AM systems will depend on milking conditions, milking duration, milking frequency and the effectiveness of the teat disinfection system.

3. Cows and milking

The milking performance of cows is significantly variable according to breed, age and genetics of the individual animals. It may be even more affected by the production methods, especially the food provision and intake. Provision of food in the milking system may condition milk let-down and improve acceptability to the AM system (Svennersten-Sjauna et al., 2000a).

Casual observation suggests that newly calved heifers milk similarly between individual quarters (Hillerton, 1996) but that time and experience changes the milking characteristics of individual quarters. At the first milkings more milk comes from front quarters, this levels out over the first lactation whilst in subsequent lactations there may be up to 60% milk from hindquarters. On average some 44% of milk comes from front teats of mature cows (Hogewerf & Ipema, 2000). These factors suggest immediately that milking according to individual quarter and not cow or, as usual in conventional systems, herd characteristics, will have significant advantages.

The time until milk flow starts and the length of milking time per quarter may also vary between quarters as well as between cows (Wendl et al., 2000). However, the overriding control of this is the method and effectiveness of teat preparation, the balance between promotional and aversive stimuli. Voluntary attendance might suggest that aversive stimuli are being minimised.

Milk flow rate may differ between cows with different teat shapes and lengths. 'Normal' shaped teats are reported to have more regular flow rates than conical teats. 'Normal' size and shape of teats is difficult to define, they are those found most commonly although there may be large differences between herds. Short teats are reported to have a higher flow rate than longer teats (Davis et al., 2000). These factors are primarily under genetic control although they may be cofactors of several effects. They will tend to be common within herds and may be of relatively little importance in the transition from conventional milking to an AM system unless significant changes are introduced e.g. in the liner type between the parlour and the AM system. To date liners have not been described for AM systems.

Quarters with a high maximum milk flow have a higher risk for intra mammary infection (Dodd & Neave, 1951; Grindal et al., 1991) simply because the dilated teat duct is wider to allow more milk flow and will take longer to close fully after milking. It is unlikely that with more frequent milkings a higher flow rate will be achieved in an AM system and so there is little risk of this being relevant, as discussed in section 2.

4. Teat condition

Teat size, shape and position may vary within a herd. In conventional milking, the person milking usually copes with such variation when attaching the teat cup through a combination of visual observation and experience. The AM system may not be so forgiving such that the success rate of teat cup attachment depends, to some extent, on a relatively uniform teat placement. A bigger problem in conventional milking is that an irregular teat or udder shape may result in misalignment of the cluster resulting in poorer milking performance, poorer teat condition and adverse response of the cows to milking (Hillerton et al., 2002a). This is less likely to be a risk with AM systems when individual teat cups are applied and the geometry of the arrangement is individual or highly variable. The arrangement may even be memorised by the operating system, programed and flexible according to inter milking interval.

AM systems may affect the milking performance according to the vacuum and pulsation conditions applied but these are compliant with best and latest knowledge, meeting the lowest risk options from extensive research (IDF, 1987). However, any adverse effects from poorer milking performance, accidental events or unusual cows will be observable by changes in teat colour, swelling, condition of the teat base, skin or especially the orifice. These conditions have been described (Hillerton et al., 2000; Mein et al., 2001) and the poor milking conditions that result in such changes are known. It is much more likely that environmental influences on the orifice and teat skin will be important in AM system milking. These may result from the milking frequency and husbandry in use or the balance between housing and grazing allowable. Management of teats is likely to be crucial to minimising any problems that may occur. The means of assessing change in teat condition are reported in section 8.

Few studies have been reported to date where teat condition was compared between an AM system and parlour milking. Ordolff & Artmann (2000) found no differences in the temperature of teats and udder, although the teat surface temperature increased more in AM system milking. Teat thickness did not differ and what was termed as extended teat canals, possibly hyperkeratosis, appeared to improve in automated milking compared to milking in a herringbone parlour. Dry skin was observed more frequently in AM system milked cows (Svennersten-Sjaunja et al., 2000b). However, in that study AM milked cows were teat sprayed and the control group teat dipped.

A key component in maintaining teat skin condition is the effectiveness of teat disinfection and post milking management. It is important to use the correct product applied to the whole teat surface. AM systems spray teats after milking, usually promptly, but not necessarily achieving good teat coverage. Generally spraying is not renowned as being the best method (Hemling et al., 2002). Problems with spraying disinfectant on to teats include use of up to twice as much chemical as dipping, difficulty in achieving high concentrations of emollients as they may block jet nozzles, poor application such that the outsides of teats may be poorly covered and much wider environmental contamination, including the milking equipment. These all appear to occur with AM systems. Reports of dry skin in AM system milking (Hovinen & Pyörälä, 2002; Rasmussen et al., 2002), predictably corrected by changing disinfectant to a formulation with more emollient, suggests insufficient attention is given to such aspects of management and that further thought and observations, especially under adverse environmental conditions, will be necessary.

5. Milking procedures

5.1 Teat preparation

Milk may be stored in the tissue alveoli or in the udder and ductal sinuses. The latter only fill progressively after a previous milking. In the absence of any stimulation, milk is removed from the sinuses and then there is usually a short delay before alveolar milk is removed. Removal of alveolar milk requires milk ejection resulting from the action of oxytocin on the myoepithelial cells of the udder. The release of oxytocin from the pituitary gland is induced by the stimulus of pre-milking procedures especially teat cleaning and fore milking. Inadequate pre-milking stimulation may result in bimodal milk flow curves, prolonged machine-on time and reduced peak milk flow but usually has no effect on total milk yield (Bruckmaier & Blum, 1996). Short milking intervals mean that more effective stimulation is necessary to avoid unnecessarily long machine attachment time and the problems that overmilking may create. Moreover, mastitis levels increase after inadequate pre-milking stimulus because of incompleteness of milking (IDF, 1987).

Teat preparation in the AM system may include cleaning all teats simultaneously, in sequence with brushes or rollers, or rinsing with water within a single dedicated preparation cup. Other stimulation for milking may come from feeding at the milking point (Svennersten-Sjaunja et al, 2000a) or vibration of the liner (Worstorff et al., 1997).

Inadequate teat preparation affects milk quality and the risk of infection. It may also lead, because of inadequate stimulation, to a period of exposure of teats to milking conditions, vacuum and pulsation, that are not relieved by milk flow. This is effectively over milking prior to flow. This may be aversive and further delay let-down as well as produce similar teat trauma to over milking after the end of milk flow. The effectiveness of teat preparation on teat condition requires evaluation in AM systems especially as more frequent milking carries a risk of slower milk availability.

5.2 Attachment

When milking in a parlour, attachment of teat cups takes a very short time and any problems are usually immediately rectifiable such that a failure to attach is virtually non-existent.

In the AM system teat cups are attached individually and in a particular sequence. First, there must be location of the teat and then attachment requires some precision in approaching the teat to ensure that the teat enters the cup. This is usually aided by vacuum.

Attachment may fail for any of a number of reasons. Early reports on AM systems were often dominated by progress in achieving better attachment success. In the more recent conferences few reports on this have been made reflecting that it is not a major problem in the commercially developed AM systems, when they operate properly. A recent field report suggests an average of fewer than 7 attachment failures per day in a herd of 57 cows milked 2.9 times per day (Dick, 2002). This is less than a 4% failure attachment rate. These are failures to milk one cow that are usually remedied by representing the cow shortly afterwards as optimisation of the system was achieved by removing the 10% of cows that had a persistent problem, most related to an uneven udder conformation. Attachment rate may be lower when cows attend the AM system less frequently and irregularly because of increased variation in relative teat placement with udder fill. Such potentially higher risks require investigation.

Individual cows may present problems that are only solved by removing the cow from the herd. This may occur when udder shape, teat placement or teat sizes are particularly extreme.

Sequentially delayed attachment of teat cups does not reduce oxytocin release and milk removal, the stimulatory effect on milk ejection of milking through a single teat cup is supposedly sufficient (Mačuhová & Bruckmaier, 2000). Few problems are likely with single-teat cup-attachment robots. However, total interruption of teat stimulation for more than 2 minutes between pre-stimulation and the start of milking means that the half-life of oxytocin may be exceeded and this may increase the amount of residual milk with consequent effects on total production and udder health (Dodd & Clough, 1962; Bruckmaier & Blum, 2001). It remains to be determined if successive failures to attach are aversive and inhibit milk let-down. This is a potential problem for teat condition as the teat will be subject to milking conditions in the absence of milk flow, a version of over milking.

5.3 Machine characteristics

5.3.1 Vacuum

The AM system is the equivalent of a single unit, low-level, conventional milking parlour. All systems developed apply the basic milking conditions and operating characteristics used in low-level parlours. They use a system vacuum of 40-44 kPa. The construction, installation and operation comply broadly with the existing standards for conventional milking (ISO, 1996) although no specific standard for AM systems has yet been developed. Further requirements may become necessary, such as specifying different standards for the milk tubes, to ensure suitable vacuum at the teat.

The AM systems in use operate so similarly to conventional milking that any effects on teat condition are unlikely to be due to the vacuum conditions directly. Excessive vacuum is only likely from poor operation of the AM system or mechanical failure as might occur in conventional milking. Modern conventional milking systems have been developed to ensure a relatively stable vacuum at the teat-end but AM systems with true quarter milking use smaller diameter milk tubes and so there may be wider cyclical variations in the teat-end vacuum (Bjerring & Rasmussen, 2002). These cyclical variations are unlikely to affect teat condition and udder health because they do not increase exposure of teats to pathogens. There is little change of irregular vacuum fluctuations or opportunity of teat end impacts as in conventional whole udder milking (Wilson, 1958; Nyhan & Cowdig, 1967). AM systems differ from conventional milking in that air admission is at each short milk tube and not a claw. A hazard is that unacceptable teat end vacuum conditions may occur if the air admission hole is inadequate or becomes blocked. The main consequence will be a flooded liner and a reduced vacuum not likely to damage the teat.

As in conventional milking, automated milking with excessive system vacuum will affect teat condition but the likelihood of observing changes in the short term is unlikely. The changes are described in section 8. Major effects are most likely from catastrophic failure and so should be detected quickly. More chronic effects may be multifactorial to be significant. This may be a combination of too high a system vacuum and over milking affecting teat end condition (Hillerton et al., 2000). Teat thickness increases during low flow rate and over milking and will decrease during high flow rate because of teat elongation (Isaksson & Lind, 1992).

5.3.2 Pulsation

Pulsation rate and ratio have been optimised for conventional milking and basic rules are known. The liner must be closed for longer than 150 ms in each pulsation cycle (ISO, 1996) to limit mastitis (Reitsma et al., 1981) and prevent any increase in teat thickness from congestion of teats (Hamann et al., 1996). Teat condition was considered to benefit if the closure was at least 290 ms (Østerås et al., 1990). However, this may only be true for certain types of liner and it is not an agreed recommendation. Too short a period of liner closure, and possibly too little load on the teat end, may affect the integrity of the teat canal and lead to increased mastitis (IDF, 1987).

The pulsation applied in AM systems is typical of that used in conventional milking and so no enhancement of risk is anticipated.

5.3.3 Liner

The liner is the only part of the milking machine that has contact with the cow's teats. The performance of the liner is controlled by its shape and composition; the teat size and shape; the vacuum applied within the liner and in the pulsation chamber; the pulsation; and the milking performance of the quarter. These factors interact. So far, the factor in an AM system most likely to be unpredictable is the effect of the liner chosen. It is clear from conventional milking systems that liner size, shape and composition can have significant effects on teats. Liner age may have a significant effect on teat condition (Hillerton et al., 2003) and must be closely controlled such that liners are not used beyond their design life. This means frequent replacement as each liner is used on all cows in the herd and not a proportion as happens in parlour milking. This is more easily monitored in the AM system where each milking and all milking conditions are recorded.

Most liners are only approximately round in cross section and after the first collapse in milking use they collapse ever afterwards in the same plane. In a milking parlour the plane of collapse relative to the teat will vary widely, yet in an AM system the liner will always collapse in the same plane on any individual teat at each milking until the liners are changed. It is unknown if repeated directional loading may influence the responses of the teat tissue as such loading does not happen in parlour milking.

Liners with a shorter mouthpiece chamber (height 30 vs. 18 mm) appear to milk faster, create fewer restless cows and result in fewer discoloured teats (Rasmussen et al., 1998). However, mouthpiece chamber and liner barrel shape may interact to create a high vacuum in the mouthpiece chamber that leads to ringing of the teat distally and cow discomfort (Newman et al., 1991). Liners mounted under higher tension, or when pulsation is impaired, fail to remove loose keratin from the teat duct and may lead to more infections (Lacy-Hulbert et al., 1996; Capuco et al., 2000). A mismatch between teat length and liner length, liners that are too short or teats that are too long, results in more mastitis (Mein et al., 1983, Rønningen & Reitan, 1990).

Liners of different shape and composition behave differently (Butler & Hillerton, 1989; de Koning & Ipema, 2000) and so may affect milking performance and teat condition in conventional milking (IDF, 1987). A major difference between conventional and AM systems is the loading applied to the teat from the hanging cluster. Cluster position has a significant effect on milking performance. This includes effects on liner slippage (O'Shea et al, 1983)

and responses of the cow, such as behaviour, milking performance and teat condition (Hillerton et al., 2000, 2002a). When teat cups hang individually below the udder in the AM system then many of the deleterious effects may be lessened but the beneficial effects e.g. milking out, may not all be achieved. Some AM systems can pull down on the teats to simulate the weight in the conventional cluster, others may require increased weight in the teat cup shell. It is far from clear what may be best in more frequently milked cows with individual quarter milking. The response of teats in the field are important and must be determined so that any changes in risk from this entirely different action of liner and ‘cluster’ can be evaluated.

5.3.4 Plant

Other than cluster weight and hang, the milking system may contribute to poorer teat condition and intra mammary infection by allowing exposure of the teat to infection. Mechanisms previously described include impacts on the teat end driving bacteria through the teat canal (Thiel et al., 1969) and physical transfer of bacteria from previously milked cows (Grindal & Bramley, 1989).

The AM systems commercially available have individual quarter milking that entirely preclude the impact mechanism. Cluster disinfection between cows is feasible in most AM systems and should aid in limiting exposure to infection. However, efficiency still requires evaluation and optimisation. The prevalence of teat end infections can be monitored to show if AM systems increase risk but the basic design and operation suggest that risk should be lessened.

5.4 Milk flow

The intention in conventional milking is for milk to flow immediately that the teat cup is attached, for flow to be sustained at a constant rate and then to end abruptly. The rectangular flow curve is optimal. This occurs frequently with first lactation animals but then progressively less so with age such that flow rate reaches a peak and then declines slowly. The rate may vary between quarters (Butler et al., 1990). The optimal curve results in

- (a) no period of machine action affecting the teat with no flow on attachment
- (b) flow quickly reaching a peak that is not excessive as the rate of intra mammary infection is proportional to peak flow rate
- (c) a rapid end of flow so that there is no over milking.

AM systems provide a major advance from true individual quarter milking by allowing take off immediately that all milk is removed from that quarter. Conventional milking only allows take off at an average flow rate when 2 or more quarters may have stopped milking or a long time after one or more quarters may have become milked-out. AM systems reduce the machine-on time for any one milking for most individual quarters.

5.5 Machine-on time

Ipema & Benders (1992) found that there was poorer teat end condition in cows milked four-times daily compared with twice daily milking and related this to a longer machine-on time per day. This does not necessarily translate to more intra mammary infection as experimentally less clinical mastitis was found with a higher milking frequency (Hillerton & Winter, 1992). Machine-on time can be shortened by increasing the switch level of cluster detachment from 200 to 400 g/min/udder and in conventional milking this was found to improve teat condition, without any adverse effects on milk yield and udder health (Rasmussen, 1993). Quarter milking will decrease the machine-on time especially on front quarters that appear to be over milked in whole udder milking (Svennersten-Sjaunja et al, 2000b). However, in conventional milking teat condition is not poorer and the incidence of mastitis is not higher in front quarters. The milking time per quarter and time until milk flow starts show differences between the quarters as well as between cows (Wendl et al., 2000) such that any effects will be individual to cows. Generally, teat condition deteriorates with over milking (Hillerton et al., 2000; IDF, 1987; Østerås et al, 1990). Poorer teat condition may also be influenced by cow factors such as low milk flow rate (Dodd & Neave, 1951) and teat end shape (Neijenhuis et al., 2000) but any effects will be mitigated by control of the milking system.

5.6 Detachment

The control of teat cup detachment for each individual teat is a major advantage of the AM system. To date, the optimal flow rate for detachment is not well defined nor has it been determined where it should be measured. This may be influenced by the frequency of milking.

5.7 Post milking

The environment has a major effect on teat condition. It is likely that AM systems in most countries will incorporate relatively good housing and regulated access to pasture such that cows will not experience poor climatic conditions or conditions differ markedly from conventional milking. Maintaining good teat skin also requires immediate post milking teat disinfection with an appropriate product (Rasmussen et al., 2002). AM systems incorporate teat spraying in the milking stall. Modern disinfectants are less aggressive chemically than even those in the recent past; however, the best formulations contain surfactants and emollients that, when sprayed to achieve sufficient coverage to manage teat condition spread relatively widely. This makes cleanliness of the milking system difficult to maintain. No obvious alternative spraying technology is available. The effects of disinfection systems should be evaluated and better systems should be sought.

6. Milking frequency

Increased frequency of milking of cows has long been known to increase milk yield (Archer, 1983; Pearson et al., 1979; Poole, 1982) and improves the persistency of lactation (Sorensen & Knight, 2000) although reports often vary according to the management in place. Similarly for the influence of increased milking frequency on udder health. Traditionally mastitis was treated, in part, by increasing the frequency and ensuring the completeness of milking (IDF, 1987). Controlled studies have shown potentially better udder health with more frequent milking (Hillerton, 1991; Klei et al., 1997). Milk somatic cell count (SCC) is usually lower in herds milked through parlours more than twice daily. When changing milking frequency there may be an initial transitory rise in SCC (van der Iest & Hillerton, 1989) but SCC decreases within a few days. It is unclear what the final effects will be for herds milked by AM systems as SCC has been shown to vary with herd and AM system, but with later generations of AM systems less likely to be associated with a rise in herd SCC (van der Vorst & Hogeveen, 2000). Automatic milking will incur unequal and variable milking intervals but Svennersten-Sjaunja et al. (2000b) found no effect on udder health. In contrast, Klungel et al. (2000) showed an increase in both SCC and milk yield after switching to automatic milking. The most recent study in this EU project has shown that with the latest installations there was no change in the SCC of milk sold off farm although the variance between farms increased (van der Vorst et al., 2002) This effect does not appear consistent between herds and so management systems may be the major influence.

Recovery of teat end thickness may take 6 to 8 hours (Neijenhuis et al., 2001) in conventional milking. Milking with shorter intervals may lead to incomplete recovery of teats (Hamann and Østerås, 1994). This could lead to an accumulation of teat trauma. However, these studies have been with conventional milking and the conditions have not been fully defined and were not necessarily optimal. It suggests that a measurable risk may occur when using an AM system, if milking intervals are short. However, many farms have milked conventionally three or four times daily for a long time and there are no obvious reports of teat condition problems on these farms. Data from one farm with an AM system showed that there was a large variation in milking interval (de Koning & Ouweltjes, 2000). 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.

7. Milking interval

Milking frequency has not been optimised for AM systems and is likely to vary with potential daily yield such that it may be four-times daily for high yielding cows and a bare twice daily for later lactation cows. The rate of milk synthesis declines after approximately 18 hours (Elliott et al., 1960) so a minimal frequency is likely to be twice daily. However, under New Zealand conditions an AM system appears effective with a frequency of one to two times daily (M. W. Woolford, personal communication). The practical milking frequency depends on the number of milkings per unit per day that is required and the number of cows that must be milked with that unit. These control the milking interval that can be sustained. Most AM systems allow management control of a minimum milking interval. Usually the interval is not less than 4 hours, to allow optimum AM system performance. Whilst some cows may volunteer to attend more frequently for part of the day depending on the stimuli, including appetite, for attendance, they will not be milked so frequently. Although a four-hour milking interval may occur occasionally it is unlikely that this will be regular in any day and long intervals will also occur. It will be important to examine the variation of milking intervals to determine if any cows are at any extended risk of being milked too frequently and if that risk can be measured by a change in teat condition.

8. Assessment of teat condition

Studies on the effects of conventional milking systems on teat condition are numerous but have suffered from a plethora of different methods of assessment, variable descriptions and use of terminology and a lack of standardisation. This has resulted in no clear consensus of cause and effect of milking conditions and teat trauma. Recently a series of reports has attempted to remedy this. The reports by Teat Club International provide agreed definitions. These include comparative descriptions of short-term machine-milking induced teat conditions (Mein et al., 2001), more chronic changes (Neijenhuis et al., 2001), environmental influences (Hillerton et al., 2002b), infectious conditions (Hillerton et al., 2001), methods of assessment that allow proper comparisons to be made between systems (Reinemann et al., 2001) and best teat management to prevent and cure less than adequate teat condition (Hemling et al., 2002).

Thus, the tools are now available to carry out studies of risk from new milking systems, methods and materials that are included in automatic milking. The tools also allow proper comparisons to be made on the relative benefits of different milking systems, changes in milking systems applied on farms and different approaches to dairy cow husbandry.

9. Benefits and hazards from AM systems

There are potential benefits and hazards from any milking system. These have been discussed earlier.

The hazards will be related to the milking conditions and the frequency of milking. Any deleterious effects of teat condition may be determined using the diagnostic and monitoring tools now available. The risk of milking with one or a few AM units as opposed to a multi point milking parlour is probably small, except for use of one liner per teat for an extended period, in comparison with the benefits of greater control available in these more sophisticated systems. Significant hazards of variable risk to teat condition and udder health are associated with various aspects of conventional milking. It should be determined how many of these exist in AM systems or if the risks are increased when using more frequent or variable frequencies of milking.

It is probably inevitable that comparison for any one farm will be between the 'new' AM system's performance and effects, and the historical achievements with what was probably an 'old' milking system, a parlour usually more than 10-years old. Modern milking technology has advanced considerable in the past 10-years and achievements with AM systems should best be compared with new parlour designs and equipment. Some of these have been shown to create new or recently recognised problems (Hillerton et al., 2000, 2002a).

Overall, benefits are more likely from the better control of milking conditions, application of modern and better maintained equipment that allows optimisation of milking performance, reduction in variation by use of one milking system only and proper quarter milking. However, it is unclear how this can be achieved so teat condition monitoring may be a necessary part of management in the AM system when the cows are not seen as often or as closely as in the milking parlour. Transfer of bacteria between cows milked in succession has been shown in parlour milking (Grindal & Bramley, 1989) but this is less likely in the AM system, although only one set of teat cups is used, as they can be rinsed or back-flushed between cows. It will be necessary to manage this use of a single set of teat cups including to change them at the correct interval. The longevity of liners to date has been taken from conventional use but the speed of effects on teat condition may not be the same.

10. Recommendations

Review of the literature on conventional milking and appraisal of AM systems suggests 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 will be associated with proper operation and management. It appears important to monitor the transition from conventional to automated milking in any herd under conversion as many other changes in operation and management will occur by default or by design. These studies should take account of the liner type, and its management, the milking interval and milking frequency to be used and determine the optimum teat cup detachment conditions. Any change in teat condition should be related to udder health and milk quality taking account also of any effects that may come from changing the means of teat preparation and teat disinfection, and general environmental management.

11. Bibliography

- Archer, P. (1983) Milking three times a day. Thames Ditton: Milk Marketing Board (*Farm Management Services Information Unit Report 34*).
- Bjerring, M. and M. D. Rasmussen (2002) Vacuum fluctuations in the liner during automatic milking. *First North American Conference on Automatic Milking, II*, Wageningen Pers, The Netherlands, pp64-66.
- Bruckmaier, R. M. and J. W. Blum (1996) Simultaneous recording of oxytocin release, milk ejection and milk flow during milking of dairy cows with and without prestimulation. *Journal of Dairy Research*, **63**: 201-208.
- Butler, M. C. and J.E. Hillerton (1989) Methods of assessing teat-cup liner performance. *Journal of Agricultural Engineering Research* **44**: 77-86.
- Butler, M. C., C. J. Allen and J. E. Hillerton (1990) Methods of measuring milking performance of cows. *Journal of Agricultural Engineering Research* **46**: 245-257.
- Capuco, A.V., D. L. Wood and J.W. Quast (2000) Effects of teatcup liner tension on teat canal keratin and teat condition in cows. *Journal of Dairy Research* **67**: 319-327.
- Davis, M. A, D. J. Reinemann and G. A. Mein (2000) Effect of liner age on milking characteristics. In: 39th Annual Meeting National Mastitis Council, Atlanta, Georgia, Sheraton Atlanta, pp. 186-187.
- de Koning, C. J. A. M. and A. Ipema (2000) Milking characteristics of 2 liners. In: *Robotic milking*. Eds. H. Hogeveen & A. Meijering, Wageningen Pers, Wageningen, pp58-59.
- de Koning, C. J. A. M. and W. Ouweltjes (2000) Maximising the milking capacity of an automatic milking system. In: *Robotic milking*. Eds. H. Hogeveen & A. Meijering, Wageningen Pers, Wageningen, pp38-46.
- Dick, G. (2002) Free access robotic milking – the next generation? *Proceedings of the British Mastitis Conference*. Institute for Animal Health/Milk Development Council, Gloucester, pp63-67.
- Dodd, F. H. and P. Clough (1962) the effect of various degrees of incomplete milking on milk and butterfat secretion. *Proceedings of the 16th International Dairy Congress*, Copenhagen, I:1, pp89-97.
- Dodd, F. H and F. K. Neave (1951) Machine milking rate and mastitis. *Journal of Dairy Research* **18**: 240-245.
- Elliott, G. M., F. H. Dodd and P. J. Brumby (1960) Variations in the rate of milk secretion in milking intervals of 2-24 hours. *Journal of Dairy research* **27**: 293-308.
- Grindal, R. J. and A. . Bramley (1989) Effect of udder preparation on transmission of *Staphylococcus aureus* while milking with a multi-valved cluster. *Journal of Dairy Research* **56**: 683-690.

- Grindal, R. J., A.W. Walton and J. E. Hillerton (1991) Influence of milk flow rate and streak canal length on new intramammary infection in dairy cows. *Journal of Dairy Research* **58**: 383-388.
- Hamann, J., G. A. Mein and B. Nipp (1996) Teat thickness changes may provide biological a test for effective pulsation. *Journal of Dairy Research* **63**: 179-189.
- Hamann, J. and O. Østerås (1994) Special aspects of teat tissue reactions to machine milking and new infection risk. *International Dairy Federation Bulletin*. No. **297**: pp35-41.
- Hemling, T. C., G. A. Mein, F. Neijenhuis, W. F. Morgan, D. J. Reinemann, J. E. Hillerton, J. R. Baines, I. Ohnstad, M. D. Rasmussen, L. Timms, J. S. Britt, R. Farnsworth and N. Cook (2002) Evaluation of bovine teat condition in commercial dairy herds: 6. Teat condition - prevention and cure through teat dips. *Proceedings of the International Mastitis Conference, Ribeirao Preto, Brazil* (in press).
- Hibbitt, K. G., C. B. Cole and B. Reiter (1969) Antimicrobial proteins isolated from the teat canal of the cow. *Journal of General Microbiology* **56**: 365-371.
- Hillerton, J. E. (1991) The effects of milking frequency on mastitis. *Proceedings of the British Mastitis Conference*, pp. 61-69.
- Hillerton, J. E. (1996) Milk yield, milkability, milking routine and udder health. In: *Proceedings of the International Symposium on Milk Synthesis, Secretion and Removal in Ruminants*. Berne, Switzerland, p91-95.
- Hillerton, J. E. and A. Winter (1992) The effects of frequent milking on udder physiology and health. In: *Proceedings of the International Symposium on Prospects for Automatic Milking*, Eds. A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing, EAAP Publication No.65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p201-212
- Hillerton, J. E., I. Ohnstad, J. R. Baines and K. A. Leach (2000) Changes in cow teat tissue created by two types of milking cluster. *Journal of Dairy Research* **67**: 309-317.
- Hillerton, J. E., W. F. Morgan, R. Farnsworth, F. Neijenhuis, J. R. Baines, G. A. Mein, I. Ohnstad, D. J. Reinemann and L. Timms (2001) Evaluation of bovine teat condition in commercial dairy herds: 2. Infectious factors and infections. *Proceedings of the 2nd International Symposium on Mastitis and Milk Quality*, NMC/AABP, Vancouver, p352-356.
- Hillerton, J. E., I. Ohnstad, J. R. Baines and K. A. Leach (2002a) Performance differences and cow responses in new milking parlours. *Journal of Dairy Research* **69**, 75-80.
- Hillerton, J. E., G. A. Mein, F. Neijenhuis, W. F. Morgan, D. J. Reinemann, J. R. Baines, I. Ohnstad, M. D. Rasmussen, L. Timms, J. S. Britt, R. Farnsworth, N. Cook and T. Hemling (2002b) Evaluation of bovine teat condition in commercial dairy herds: 5. Environmental factors. *Proceedings of the International Mastitis Conference, Ribeirao Preto, Brazil* (in press).
- Hillerton, J. E., D. Boast, D. Davies, I. Ohnstad and N. Middleton (2003) Changes in milking liner performance with age. *Proceedings of the 4th Dairy Housing Conference, Fort Worth TX*, (in press).

- Hogeveen, H., W. Ouweltjes, C. J. A. M. de Koning and K. Stelwagen (2001) Milking interval, milk production and milk flow-rate in an automatic milking system. *Livestock Production Science* **72**: 157-167.
- Hogewerf, P. H. and A. H. Ipema (2000) Analysis of differences in yield and milk flow properties between front and rear quarters. In: *Robotic milking*. Eds. H. Hogeveen & A. Meijering, Wageningen Pers, Wageningen, pp60-61.
- Hovinen, M. and S. Pyörälä (2002) Observations on udder health of automatically milked cows in Finland. *First North American Conference on Automatic Milking*, Wageningen Pers, The Netherlands, IV, 71-74.
- IDF (1987) Machine milking and mastitis. *Bulletin of the International Dairy Federation* **No 215**, IDF, Brussels.
- van der Iest, R. and J. E. Hillerton (1989) The short-term effects of frequent milking of dairy cows. *Journal of Dairy Research* **56**: 587-592.
- Ipema, A. H. and E. Benders (1992) Production, duration of machine-milking and teat quality of dairy cows milked 2, 3 or 4 times daily with variable intervals. In: *Proceedings of the International Symposium on Prospects for Automatic Milking*, Eds. A. H. Ipema, A. C. Lippus, J. H. M. Metz & W. Rossing, EAAP Publication No.65, Pudoc Scientific Publishers, Wageningen, The Netherlands, pp244-252.
- ISO (1996) ISO5707 Milking machine installations - construction and performance. International Standards Organisation.
- Isaksson, A. and O. Lind, 1992. Teat reactions in cows associated with machine milking. *Journal of Veterinary Medicine* **A39**: 282-288.
- Klei, L. R., J. M. Lynch, D. M. Barbano, P. A. Oltenacu, A. J. Lednor and D. K. Bandler (1997) Influence of milking three times a day on milk quality. *Journal of Dairy Science* **80**: 427-436.
- Klungel, G. H., B. A. Slaghuis and H. Hogeveen (2000) The effect of the introduction of automatic milking systems on milk quality. *Journal of Dairy Science* **83**:1998-2003.
- Lacy-Hulbert, S. J. and J. E. Hillerton (1995) Physical characteristics of the teat canal and their influence on susceptibility to streptococcal infection. *Journal of Dairy Research* **62**: 395-404.
- Lacy-Hulbert, S. J., J. E. Hillerton and M. W. Woolford (1996) Influence of pulsationless milking on teat canal keratin growth and turnover. *Journal of Dairy Research* **63**: 517-524.
- Mačuhová, J. and R. M. Bruckmaier (2000) Oxytocin release, milk ejection and milk removal in the Leonardo multi-box automatic milking system. In: *Robotic milking*. Eds. H. Hogeveen & A. Meijering, Wageningen Pers, Wageningen, pp184-185.
- Mein, G. A., M. R. Brown and D. M. Williams (1983) Pulsation failure as a consequence of milking with short teatcup liners. *Journal of Dairy Research* **50**: 249-258.

- Mein, G. A., F. Neijenhuis, W. F. Morgan, D. J. Reinemann, J. E. Hillerton, J. R. Baines, I. Ohnstad, M. D. Rasmussen, L. Timms, J. S. Britt, R. Farnsworth, N. Cook and T. Hemling (2001) Evaluation of bovine teat condition in commercial dairy herds: 1. Non-infectious factors. *Proceedings of the 2nd International Symposium on Mastitis and Milk Quality*, NMC/AABP, Vancouver, p374-351.
- Neijenhuis, F., H. W. Barkema, H. Hogeveen and J. P. T. M. Noordhuizen (2000) Classification and longitudinal examination of callused teat ends in dairy cows. *Journal of Dairy Science* **83**: 2795-2804.
- Neijenhuis, F., G. H. Klungel and H. Hogeveen (2001) Recovery of cow teats after milking as determined by ultrasonographic scanning. *Journal of Dairy Science* **84**: 2599-2606.
- Neijenhuis, F., G. A. Mein, J. S. Britt, D. J. Reinemann, J. E. Hillerton, R. Farnsworth, J. R. Baines, T. Hemling, I. Ohnstad, N. Cook, W. F. Morgan and L. Timms (2001) Evaluation of bovine teat condition in commercial dairy herds: 4 Relationship between teat-end callosity or hyperkeratosis and mastitis. *Proceedings of the 2nd International Symposium on Mastitis and Milk Quality*, NMC/AABP, Vancouver, p362-366.
- Newman, J. A., R. J. Grindal and M. C. Butler (1991) Influence of liner design on mouthpiece chamber vacuum during milking. *Journal of Dairy Research* **58**: 21-27.
- Nyhan, J. F. and M. J. Cowdig (1967) Inadequate milking machine reserve and mastitis. *Veterinary Record* **81**: 122-124,
- O'Shea, J., E. O'Callaghan and W. Meaney (1983) Milking performance and liner design and slips. *Proceedings of the 22nd Annual Meeting of the National Mastitis Council*, Kentucky, USA, pp4-14.
- Ordolff, D. and R. Artmann (2000) Surface temperatures of udder and teats conventional and automatic milking systems. In: *Robotic milking*. Eds. H. Hogeveen & A. Meijering, Wageningen Pers, Wageningen, p301.
- Østerås, O., I. Vagsholm and A. Lund, 1990. Teat lesions with reference to housing and milking management. *Journal of Veterinary Medicine* **A37**: 520-524.
- Pearson, R. E., L. A. Fulton, P. D. Thompson and J. W. Smith (1979) Three times a day milking during the first half of lactation. *Journal of Dairy Science* **62**: 1941-1950.
- Poole, D.A. (1982) The effects of milking cows three times a day. *Animal Production* **34**: 197-201.
- Rasmussen, M. D. (1993) Influence of switch level of automatic cluster removers on milking performance and udder health. *Journal of Dairy Research* **60**: 287-297.
- Rasmussen, M. D., L. Foldager and T. C. Hemling (2002) Teat conditioning, udder health and frequency of milking: impact of teat dip composition. *Proceeding of the DeLaval Hygiene Technology Center Inaugural Symposium*, Kansas City MO, pp16-23.

- Rasmussen, M. D., E. S. Frimer, L. Kaartinen and N. E. Jensen (1998) Milking performance and udder health of cows milked with two different liners. *Journal of Dairy Research* **65**: 353-363.
- Reinemann, D. J., M. D. Rasmussen, S. LeMire, F. Neijenhuis, G. A. Mein, J. E. Hillerton, W. F. Morgan, L. Timms, N. Cook, R. Farnsworth, J. R. Baines & T. Hemling (2001) Evaluation of bovine teat condition in commercial dairy herds: 3. Getting the numbers right. *Proceedings of the 2nd International Symposium on Mastitis and Milk Quality*, NMC/AABP, Vancouver, p357-361.
- Reitsma, S.Y., E. J. Cant, R. J. Grindal, D. R. Westgarth and A. J. Bramley (1981) Effect of duration of teat cup liner closure per pulsation cycle on bovine mastitis. *Journal of Dairy Science* **64**: 2240-2245.
- Rønningen, O. and A. D. Reitan (1990) Teat length and penetration into the teat cup during milking of Norwegian Red Cattle. *Journal of Dairy research* **57**: 165-170.
- Sorensen, A. and C. H. Knight (2000) Effect of milking frequency, nutrition and calving season on lactation persistency. *Proceedings of the 51st Annual Meeting of the EAAP*, The Hague, The Netherlands, p215.
- Svennersten-Sjauna, K., B. Johansson, I. Redbo and K. Uvnåa-Moberg (2000a) The effect of feeding during milking on oxytocin release, milk production, milking parameters and cow behaviour. In: *Robotic milking*. Eds. H. Hogeveen & A. Meijering, Wageningen Pers, Wageningen, p196.
- Svennersten-Sjauna, K., I. Berglund and G. Petterson (2000b) The milking process in an automatic milking system, evaluation of milk yield, teat condition and udder health. In: *Robotic milking*. Eds. H. Hogeveen & A. Meijering, Wageningen Pers, Wageningen, pp277-288.
- Thiel, C. C., C. L. Thomas, D. R. Westgarth and B. Reiter (1969) Impact force as a possible cause of mechanical transfer of bacteria to the interior of the cow's teat. *Journal of Dairy Research* **36**: 279-297.
- van der Vorst, Y. and H. Hogeveen (2000) Automatic milking systems and milk quality in the Netherlands. In: *Robotic milking*. Eds. H. Hogeveen & A. Meijering, Wageningen Pers, Wageningen, pp73-82.
- Van der Vorst, Y., K. Knappstein and M. D. Rasmussen (2002) Effects of automatic milking on the quality of produced milk. EU project *Implications of the introduction of automatic milking on dairy farms* (QLK5 -2000-31006), 22pp.
- Wendl, G., J. Harms and D. Schön (2000) Analysis of milking behaviour on automatic milking. In: *Robotic milking*. Eds. H. Hogeveen & A. Meijering, Wageningen Pers, Wageningen, pp143-151.
- Wilson, C. D. (1958) Factors that predispose to mastitis with special reference to milking technique. *Veterinary Record* **70**: 159-166.
- Worstorff, H., R. Fischer and I. Arpe (1997) Mechanical pre stimulation and milk release with special regard to pulsation and time. *Milchwissenschaft-Milk-Science-International* **52**: 183-187.