Milking Performance of Dairy Cows Subjected to Electrical Current and Induced Milking Machine Problems

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Abstract. *Milking performance of cows subjected to electrical current during milking and two common milking machine problems were documented. The first experiment used 32 cows in a 2 × 2 factorial design with exposure to 1 mA (rms, 60 Hz) of electrical current from front to back hooves during milking and a pulsation failure (no massage phase) as treatments. A second experiment used 16 cows in a 2 × 2 factorial design with exposure to 1 mA (rms, 60 Hz) of electrical current from front to back hooves during milking and excessively aged milking machine liners as treatments. The response measures for both experiments were milk yield, average milk flow rate, maximum milk flow rate, cow activity, and strip yield.*

The main effect of current exposure was not statistically significant for any of the response variables. The main effect of pulsation failure was significant for cow activity (5.8 fewer weight shifts during a milking). The main effect of aged liners was significant for milk yield (2.2 kg increase), average flow rate (0.3 kg/min reduction), maximum flow rate (1.2 kg/min reduction), and liner slips (26 more per milking). The significance of some interactive effects appeared to indicate that current exposure had a mitigating effect on the changes caused by the milking machine problems. These interactions were not consistent across experiments and in some cases were highly influenced by a few observations. Further investigation is warranted before drawing any firm conclusions regarding these interactive effects.

This study adds further evidence to the body of literature showing that exposure to low–level step potential resulting in ≤1 mA rms of 60 Hz electrical current during milking is not a cause of cow discomfort or poor milking performance.

Keywords. *Stray voltage, Machine milking, Milk flow.*

Several studies have been performed to examine the changes in behavior and milking performance of dairy cows in response to electrical exposure during milking. Lefcourt and Akers (1982) applied 5 mA (rms, 60 Hz) of current continuously and intermittently through ECG electrodes attached to abraded skin at the front knee and rear hock of 6 Holstein cows. Behavioral responses such as leg lifting were observed for both continuous and intermittent exposures. Continuous exposure resulted in no significant effect on milk yield or milking time but did increase the oxytocin response to milking stimuli. Intermittent exposure resulted in a decrease in milk yield and milking time. The oxytocin response to milking stimuli was increased and prolactin response inhibited.

Lefcourt et al. (1985) reported on another series of experiments in which cows were exposed to intermittent currents of 3.6 and 6.0 mA (rms, 60 Hz) through ECG electrodes attached to abraded skin on the front and rear leg for 14 milkings. Behavioral changes were observed at both exposure levels, but changes in milk yield, milking time, and somatic cell count (SCC) were not significant. A delay in the oxytocin peak was observed at the 3.6 mA exposure but not at the 6.0 mA level.

Cows exposed to 4 and 8 mA (rms, 60 Hz) of electrical current between electrodes attached to the udder and four hooves during milking showed some behavioral responses that decreased with time (Henke et al., 1985). This study suggested that some cows showed a behavioral response to 2 mA, and most cows showed a clear behavioral response to 4 mA. Changes in milking performance and milk composition were not significant at the 4 or 8 mA exposure levels. Changes of milking–related cortisol responses during application of 8 mA (rms, 60 Hz) were significant.

Alternating currents were applied through the milk during milking in a study by Aneshansley et al. (1992). They reported that first–lactation cows kicked at the milking unit when current exceeded 5 mA (8 V rms, 60 Hz). Multiple–lactation cows began kicking at currents above 8 mA (16 V rms, 60 Hz). There were no undesired behaviors or consistent significant differences in milking duration, milk yield, or composition for primary or residual milk for current application below these levels. Application of constant currents of 5 mA (rms, 60 Hz) for first–lactation cows and 8 mA (rms, 60 Hz) for multiple–lactation cows produced no undesired behaviors but did result in some differences in milking performance. Milking duration decreased during

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application of constant current to first–lactation cows. Serum cortisol concentrations increased from 5 ng/mL before milking to 15 ng/mL measured 10 min after milking. Cows exposed to 8 mA (rms, 60 Hz) of current during milking had slightly reduced serum cortisol concentration 2 and 6 min after milking as compared to control cows.

Previous research suggests that current exposure during milking can influence behavior; however, the exposure level at which these effects have been documented ranges from 3.6 to 8 mA (rms, 60 Hz). Anecdotes from the field suggest that increased cow activity during milking (stepping and kicking) may be attributable to current exposure of less than 1 mA (rms, 60 Hz) through cows. These reports have not been documented in a controlled study. This study was conducted to test the hypothesis that low–level voltage/current exposure could produce behavioral responses or changes in milking characteristics. The specific objectives of this study were to:

1. Measure changes in milking performance of cows exposed to low–level (1 mA rms, 60 Hz) current during milking.
2. Measure changes in milking performance of cows exposed to commonly encountered milking machine problems.
3. Compare low–level current responses to milking machine stress responses.

Materials and Methods

Experiments were designed as completely randomized two–level factorials ($CRF_{2,2}$). In the first experiment, the treatments were 1 mA (rms, 60 Hz) current applied from front to rear hooves during milking and a pulsator failure producing no d–phase (or massage phase) of pulsation. In the second experiment, the two treatments were 1 mA (rms, 60 Hz) current applied from front to rear hooves during milking and excessively aged liners.

Cows were randomly selected from the available pool of approximately 80 cows in the research barn and then randomly assigned to one of the four study conditions (no treatment, electrical current exposure, induced milking machine problem, or combination of electrical current and induced milking machine problem). The cows used in this study were in their 1st to 7th lactation and producing 27 to 49 kg of milk per day. These experiments were conducted in one stall of the four–stall milking parlor in the UW–Madison Dairy Cattle Research and Instruction Center. The milking machine specifications include: a low–level milkline, Bou–Matic Flow Star Claws, milking vacuum level of approximately 36 kPa in the claw, and a pulsation ratio of 60:40. Automatic detachers with a removal threshold of 0.45 kg/min of milk flow and a 5 s detachment delay were used for all tests. The milking machine was allowed to automatically detach without any human interference for all tests.

Tests were performed during three consecutive evening milkings. All cows were milked using normal procedures and equipment on the first and third evenings' milkings. The treatments were administered on the second evening's milking. The same operator milked all the cows used in this study for the three nights of testing. The response variables measured in these studies were milk yield, strip yield, maximum milk flow rate, average milk flow rate, liner slips, and cow activity. Responses were calculated as the difference between the value on the treatment day and the average of the two control days (before and after treatment day) for each cow.

Milk yield was recorded using the milk meters installed in the UW parlor (Bou–Matic, Perfection). Strip yield was measured by hand milking immediately after the automatic detacher removed the milking unit. The number of quarters that yielded more than 10 mL of milk was recorded for each cow. The milk flow rate was measured by a computer–based data acquisition system interfaced with the milk meter to record milk flow rate every 5 s. The maximum milk flow rate was taken as the maximum 30–s rolling average of the milk flow rates. Average milk flow rate was taken as the milk yield divided by the milking time. Milking vacuum was measured in the short milk tube, as recommended by Reinemann et al. (2001). The time of milking was taken as the interval during which the 5–s average milking vacuum was greater than 5 kPa. Liner slips were defined as a drop in milking vacuum exceeding 14 kPa with a rate of change exceeding 56 kPa/s (Davis et al., 2000).

Cow activity was quantified by monitoring the load cell placed under one edge of the rear aluminum plate in the parlor stall (fig. 1). The plates were supported by rubber strips around the edges and across the center of the plates. The rear plate was fitted with a load cell on one edge. Load was measured at a frequency of 100 Hz. An activity event (weight shift) was defined as a change in load over time in excess of 25 kg/s. This rate of change in load corresponded approximately to a cow lifting its hoof, as confirmed by human observers. The aluminum plates were less sensitive to weight changes than the suspended stalls used in previous studies (Reinemann et al., 1999) because they were supported around their perimeter with rubber strips to provide electrical isolation from the parlor floor.

Current Exposure

A schematic of the current exposure apparatus is shown in figure 2. Two aluminum plates were placed in the milking stall for several days prior to testing and for all three days during testing. When current exposure was specified, a voltage was applied from the front to rear plates when the milking unit was attached to the cow. A technician adjusted the source resistance while monitoring the current flow with

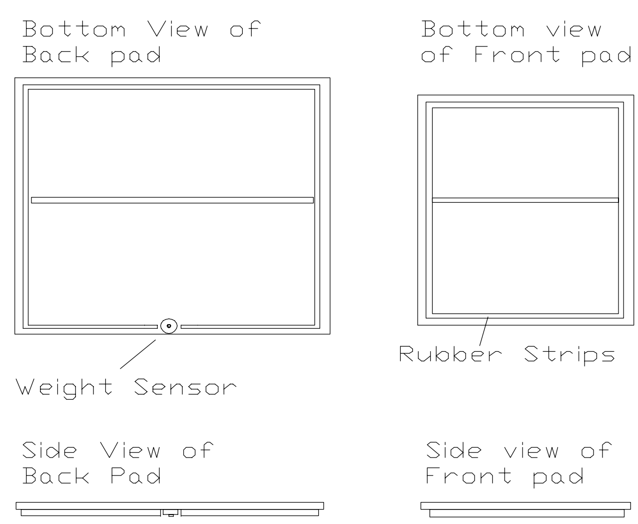

Figure 1. Activity monitoring device for milking time tests.

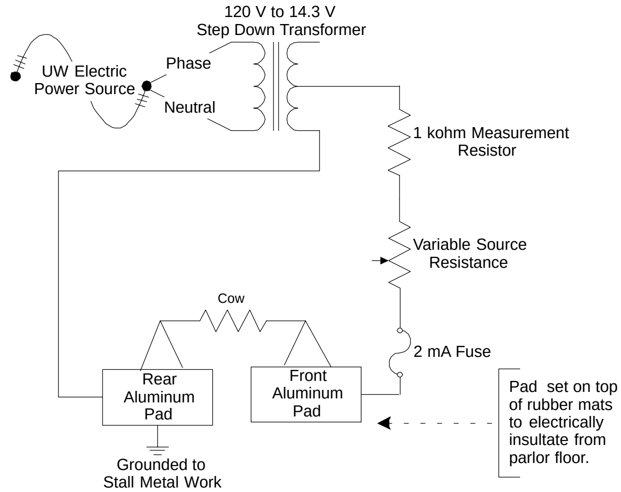

Figure 2. Schematic of electrical apparatus for milking time tests.

an oscilloscope (Tektronix model 720) so that 1 mA (rms, 60 Hz) current was passing through the cow for the duration of the milking. The waveform of the current was sinusoidal. The voltage and current application was removed when the milking unit detached.

Induced Milking Machine Problems

Pulsation Failure. For treatments requiring pulsation failure, a one–way valve was placed in each of the two long pulse tubes. This one–way valve allowed the pulsation chamber to be evacuated (opening the liner) in its normal fashion. When the pulsation chamber was opened to atmospheric pressure, the valve would shut and prevent the liner from closing completely. This resulted in the absence of the d phase of pulsation. The d, or massage, phase of pulsation provides relief to teat tissues from the stresses imposed by milking vacuum.

Aged Liners. The liners used for this study (Bou–Matic R–2CV) were artificially aged by soaking them in clarified butter oil at 100° C for 72 hours (Davis et al., 1999). This artificial aging process decreased the average mounted barrel tension from 74 N to 38 N, and increased the average mouthpiece lip flex under a 0.5 kg load from 7.83 mm to 12.40 mm.

Statistical Analysis

Each observation was the change in the response variable for each cow on the treatment day from the average of the value on the day before and the day after the treatment day. ANOVA was performed on these changes in response using the GLM procedure of SAS for the main effects of current exposure (CE) and milking stress (MS), and the interactive effect (CE × MS). The main and interactive effects of the change in response due to the treatment were considered significant if the change in response was different from zero with a p values less than 0.05. This analysis was performed for each of the experiments separately:

- 2 × 2 factorial with current exposure and pulsation failure (n = 32)
- 2 × 2 factorial with current exposure and aged liners (n = 16).

Additional analysis for current exposure only was also performed using one–way ANOVA (current exposure vs. no current exposure) using the combined data sets from both experiments. Effects were considered significant for p values less than 0.05.

Results

Results for the experiments using pulsation failure and current exposure as treatments are shown in table 1. This analysis is for 2 replicates of 16 cows each, for a total of 32 cows. The failure of a vacuum transducer during the second replicate resulted in the loss of slip data for the second set of 16 cows. None of the responses showed a statistically significant effect of current exposure. Pulsation failure produced a significant decrease in cow activity with an average of 5.8 fewer steps for those cows experiencing pulsation failure. The decrease in milk yield, average flow rate, and maximum flow rate approached significance for the pulsation failure treatment.A significant interactive effect between current exposure and pulsation failure was noted for milk yield and cow activity. Details of the interactive effects on milk yield and activity are shown in table 2.

There was a small increase in milk yield (+0.1 kg) on the treatment day for the 8 cows not exposed to either treatment. There was a decrease in milk yield for the 8 cows exposed to pulsation failure only (–0.3 kg) and the 8 cows exposed to current only (–1.3 kg). Cows exposed to both current and a pulsation failure had an increased yield (+1.4 kg). The main effect of current on milk yield averaged over 16 cows was very small (0.1 kg) and not significant ($p = 0.86$). The main effect of pulsation failure on milk yield averaged over 16 cows approached a significant increase ($p = 0.10$). The

Table 1. Main and interactive effects of pulsation failure and 1 mA (rms, 60 Hz) current exposure during milking on milk yield and milking performance.

Response Variable	1 mA Current Exposure	Pulsation Failure	Standard Error	Interactive Effect
Milk yield (kg)	0.12	1.17 [a]	0.68	3.11 [b]
Average flow rate (kg/min)	0.10	0.20 [a]	0.10	0.32
Max. flow rate (kg/min)	0.04	0.29 [a]	0.16	–0.14
Activity (weight shifts)	–1.3	–5.8 [d]	1.4	8.9 [c]
Strip yield (% of quarters >10 mL)	8.6	–10	6.8	–14
Liner slips	0.6	–0.6	0.67	0.75

Significance of effects indicated by:
[a] $p < 0.1$
[b] $p < 0.05$
[c] $p < 0.005$
[d] $p < 0.001$.

Table 2. Least square means illustrating interactive effect of 1 mA (rms, 60 Hz) of current exposure and pulsation failure on milk yield and cow activity.

Pulsation Failure	Current Exposure	n	Milk Yield (kg) LSM[a]	Milk Yield (kg) SD[b]	Activity Events LSM	Activity Events SD
No	No	8	+0.1	1.6	+5.5	1.8
No	Yes	8	–1.3	2.0	–0.3	5.1
Yes	No	8	–0.3	2.2	–4.8	4.5
Yes	Yes	8	+1.4	2.0	–1.6	3.5

[a] LSM = least square mean difference.
[b] SD = standard deviation.

interactive effect of current was thus to counteract the apparent change in milk yield produced by pulsation failure.

Cows not exposed to either treatment showed an average increase in activity during milking (+5.5 events). Cows exposed to only pulsation failure showed an average decline in activity (–4.8 events), while cows exposed to current only had very small average decline in activity (–0.3 events). The 8 cows exposed to both pulsation failure and current showed a slight decline in activity (–1.6 events). The main effect of current was small and not significant (–1.3 events, $p = 0.36$), while the main effect of pulsation failure was a significant decrease in activity (–5.8 events, $p = 0.0002$). The interactive effect of current thus appeared to counteract the reduced activity resulting from pulsation failure. The significance of this interaction was highly influenced by increased activity of cows receiving no treatment and is therefore questionable.

Results of the experiment using aged liners and current exposure as treatments are shown in table 3. There was no statistically significant effect of current exposure on any of the response variables. The aged liner treatment produced statistically significant results for milk yield (2.2 kg increase), average milk flow rate (0.3 kg/min decrease), maximum milk flow rate (1.2 kg/min decrease), and liner slips (26 increase).

The interactive effect between current exposure and aged liners was significant for the strip yield response. Details of the interactive effects on strip yield are shown in table 4. There was a small decrease in strip yield (–3% of quarters with >10 mL of milk) for cows not exposed to either treatment. There was an increase in strip yield for cows exposed to either treatment alone (+16% for current exposure, +28% for aged liners). Cows exposed to both current and aged liners showed a decrease in the percentage of quarters with >10 mL of strip yield (–8%). Neither main effect for current nor aged liners was significant. The interactive effect of current exposure in combination with aged liners appeared to be more complete milking. The significance of this interactive effect was highly influenced, however, by one cow that milked more completely when exposed to both aged liners and current exposure (no quarters >10 mL) compared to her control days (2 and 3 quarters >10 mL).

The results of the one–way ANOVA examining the effect of current exposure are shown in table 5. The random selection process of the available pool of cows resulted in

Table 3. Main and interactive effects of milking with aged liners and 1 mA (rms, 60 Hz) current exposure on milk yield and milking performance.

Response Variable	1 mA Current Exposure	Aged Liners	Standard Error	Interactive Effect
Milk yield (kg)	–0.60	2.21 [c]	0.67	–0.98
Average flow rate (kg/min)	–0.06	–0.34 [b]	0.13	–0.04
Max. flow rate (kg/min)	–0.26	–1.19 [d]	0.25	–0.88
Activity (weight shifts)	–0.3	–8.9	6.3	–5.9
Strip yield (% of quarters >10 mL)	–15	–3.1	10	–69 [c]
Liner slips	–0.9	26 [d]	2.5	–2.1

Significance of effects indicated by:
[a] $p < 0.1$
[b] $p < 0.05$
[c] $p < 0.005$
[d] $p < 0.001$.

Table 4. Least square means illustrating interactive effect of 1 mA (rms, 60 Hz) of current exposure and aged liners on strip yield measured as the % of quarters with more than 10 mL of milk hand stripped.

Aged Liners	Current Exposure	n	Strip Yield (% quarters >10 mL) LSM[a]	SD[b]
No	No	4	–3	21
No	Yes	4	16	12
Yes	No	4	28	16
Yes	Yes	4	–22	30

[a] LSM = least square mean difference.
[b] SD = standard deviation.

Table 5. Effects of 1 mA (rms, 60 Hz) current exposure during milking on milk yield and milking performance (n = 48).

Response Variable	Mean Effect	Standard Error	p value
Milk yield (kg)	0.12	0.59	0.84
Average flow rate (kg/min)	–0.05	0.09	0.61
Maximum flow rate (kg/min)	0.06	0.18	0.76
Activity (weight shifts)	1.0	2.6	0.71
Strip yield (% of quarters >10 mL)	–0.5	6.7	0.94
Liner slips	0.2	4.3	0.97

some cows being used across experiments. Experimental trials were separated by a minimum of one month, and the treatments applied to non–unique cows were not repeated. The results in table 5 are for the entire set of 48 observations. No significant effect of current exposure on any of the response variables was found. The analysis was repeated using data from only a unique group of cows, and the significance of the results did not change.

Discussion

Behavioral changes have been reported in cows exposed to electrical currents during milking at exposure levels of:

- 5 mA (rms, 60 Hz) by Lefcourt and Akers (1982)
- 3.6 and 6.0 mA (rms, 60 Hz) by Lefcourt et al. (1985)
- 4 mA and 8 mA (rms, 60 Hz) by Henke et al. (1985)
- 5 mA and 8 mA (rms, 60 Hz) by Aneshansley et al. (1992).

Hormonal responses were reported in some of these studies, generally at the higher exposure levels. The method of applying current in all of these studies was not typical of exposures in the field. In the first three studies cited above, current was applied through electrodes attached to the skin of legs or udders. In the fourth study, current was applied through an electrode in the milk stream of the short milk tube. Reports from the field have continued to attribute increased activity during milking and poor milking performance to current exposure below 1 mA (rms, 60 Hz). The experiments reported here were performed to further investigate these claims and to use a more typical exposure pathway: a step potential from front to rear hooves.

A number of stresses have been shown to influence milking performance and cow behavior during milking. Rushen et al. (1999) found a 70% increase in residual milk when cows were exposed to adverse and unpredictable stresses during milking. However, predictable adverse interaction (hitting cows' noses) during milking did not change the amount of residual milk left after milking (Munksgaard, 2000). Changes in cow handling procedures produced a change in the milk yield of herds from +23% to –36%

(Seabrook, 1994). Cows handled adversely were reported to dung more during milking and have a shorter flight distance than those handled favorably (Seabrook, 1994).

Cows release the hormone oxytocin during milking to contract the alveoli in the udder and eject milk. It is generally understood that stresses during milking may reduce the release of oxytocin (Bruckmaier and Blum, 1998) and thereby reduce milk yield and affect milking performance. The maximum and average milk flow rates may be affected by changes in the milking machine and could also be affected by changes in the oxytocin release of cows during milking. Strip yield is a measure of the completeness of milk removal by the milking machine. Strip yield may be affected by changes in the milking machine and is also another measure of changes in endocrine response during milking. Changes in milk flow rate or strip yield could, therefore, be an indication of an endocrine response of cows due to current exposure and/or other discomfort during milking. We did not observe any changes in milking performance that would indicate discomfort or an aversive endocrine response in diary cows exposed to 1 mA of current during milking.

The lack of pulsation has been shown in previous studies to cause congestion of teat tissue (Hamann et al., 1994) and presumably discomfort to cows (Bramley et al., 1978). A malfunctioning pulsator is a commonly encountered problem in the field and was expected to produce mild discomfort to cows, possibly resulting in increase activity during milking. We observed, however, a significant decrease in activity when pulsation failure was applied. Kicking at the milking unit is often coincident with the start of over–milking and is likely due to the increased physical stress on the teat tissue during this period. Over–milking (milking unit remains attached after milk flow rate falls below 0.5 kg/min) is a common occurrence on commercial dairy farms. The detacher setting used in our experiments minimized the period of over–milking. It is speculated that pulsation failure in the beginning of milking may have reduced the milking time and produced no averse effects during these experiments since the over milking period was reduced to a minimum.

The use of aged liners produced a significant increase in the number of liner slips in these experiments. This was probably due to deformation or reduced stiffness of the liner mouthpiece lip, resulting in a poorer seal between the liner lip and the teat. Aged liners may also have a reduced coefficient of friction between the liner and teat skin. When these conditions exist, more air is admitted into the liner and milking vacuum is reduced. This is consistent with the observation of increased milking time and decrease in the average milk flow rates. These results are in agreement with the general observation from the field of faster milking when liners are changed. Surprisingly, milk yield increased when milking with aged liners. However, the milking interval and milking order were not controlled during this experiment, which may have influenced this result. Furthermore, literature reports of increase (Kelly et al., 1983; O'Shea and O'Callaghan, 1980), no response (Davis et al., 2000), and decrease in milk yield (Gleeson and O'Callaghan, 1998) have also been reported when using aged liners. The change in milk yield with aged liners appears to be a complex combination of many factors as yet unexplained.

Given the ample evidence of changes in milking performance and cow behaviors that can be caused by human/cow interactions and sub–optimal milking machine performance, and the lack of response to low–level currents in controlled studies, it is unlikely that low–level current exposure is a contributor to the milking problems observed in the field.

CONCLUSIONS

Several significant effects on milking performance were measured when commonly encountered milking machine problems (pulsation failure and aged liners) were applied to cows in this study. Exposure to 1 mA (rms, 60 Hz) of current from front to rear hooves during milking produced no significant change in milk yield, milk flow rate, strip yield, cow activity, or liner slips in this study. The significance of some interactive effects appeared to indicate that current exposure had a mitigating effect on the changes caused by the milking machine problems. These interactions were not consistent across experiments and in some cases were highly influenced by a few observations. Further investigation is warranted before drawing any firm conclusions regarding these interactive effects.

While it has been clearly shown in previous studies that cow behavior during milking can be affected by current exposures of 3.6 mA and above, all indications from this study are that current exposure of 1 mA (rms, 60 Hz) or less from front to rear hooves has no adverse effects on cow behavior or milking performance. This study adds further evidence to the body of literature showing that exposure to low–level step potential resulting in $\leq$1 mA rms of 60 Hz electrical current exposure during milking is not a cause of cow discomfort or poor milking performance.

REFERENCES

Aneshansley, D. J., R. C. Gorewit, and L. R. Price. 1992. Cow sensitivity to electricity during milking. *J. Dairy Sci.* 75(10): 2733–2741.

Bramley A. J., T. K. Griffin, and R. J. Grindal. 1978. Some investigations on the effects of continuous vacuum milking on new infection of the udders. In *Proc. Int. Symp. on Machine Milking 17*, 291–300. Madison, Wisc.: National Mastitis Council.

Bruckmaier, R. M., and J. W. Blum. 1998. Oxytocin release and milk removal in ruminants. *J. Dairy Sci.* 81(4): 939–949.

Davis, M. A., D. J. Reinemann, and G. A. Mein. 1999. Measurement of change of liner properties with age. ASAE Paper No. 993017. Written for presentation at the 1999 ASAE/CSAE International Meeting. Toronto, Ontario, Canada. July 18–21. St. Joseph, Mich.: ASAE.

_____. 2000. Effect of liner age on milking characteristics. In *Proc. National Mastitis Council 39*,186–187. Madison, Wisc.: National Mastitis Council.

Gleeson, D. E., and E. J. O'Callaghan. 1998. A note on the effect of aging on teatcup liner performance. *Irish J. Agricultural and Food Res.* 37(1): 93–95.

Hamann, J., O. Osteras, M. Mayntz, and W. Woyke. 1994. Functional parameters of milking units with regard to teat tissue treatment. In *Bulletin of the International Dairy Federation*. No. 297: Teat tissue reactions to machine milking and new infection risk, 23–24. Brussels, Belgium: International Dairy Federation

Henke, D. V., R. C. Gorewit, N. R. Scott, and R. Sagi. 1985. Milk production, health, behavior, and endocrine responses of cows exposed to electrical current during milking. *J. Dairy Sci.* 68(10): 2694–702.

Kelly, T. G., B. McKenna, and J. O'Shea. 1983. Milking machine liners: A review of their chemical and physical characteristics and factors affecting their deterioration. In *Milking Machine Res. at Moorepark 1978–82*, 14–23. Dublin, Ireland: An Foras Taluntais.

Lefcourt, A. M., and R. M. Akers. 1982. Endocrine responses of cows subjected to controlled voltages during milking. *J. Dairy Sci*. 65(11): 2125–2130.

Lefcourt, A. M, R. M. Akers, R. H. Miller, and B. Weinland. 1985. Effects of intermittent electrical shock on responses related to milk ejection. *J. Dairy Sci*. 68(2): 391–401.

Munksgaard, L. 2000. Personal communication. Danish Institute of Agricultural Sciences.

O'Shea, J., and E. O'Callaghan. 1980. Milking performance of clusters with standard pulsation. In *Experiments on Milking Machine Components at Moorepark 1976–79*, 142. Dublin, Ireland: An Foras Taluntais.

Reinemann, D. J., L. E. Stetson, J. P. Riley, N. K. Laughlin. 1999. Sensitivity of dairy cows to short–duration currents. *Trans. ASAE* 42(1): 215–222.

Reinemann, D. J., M. D. Rasmussen, and G. A. Mein. 2001. Instrument requirements and methods for measuring vacuum in milking machines. *Trans. ASAE* 44(4): 975–981.

Rushen, J., A. M. B. De Passille, and L. Munksgaard. 1999. Fear of people by cows and effects on milk yield, behavior, and heart rate at milking. *J. Dairy Sci*. 82(4): 720–727.

Seabrook, M. F. 1994. Psychological interactions between the milker and the dairy cow. In *Proc. National Mastitis Council Annual Meeting 33*, 163–172. Madison, Wisc.: National Mastitis Council.