Effect of Duration of Teat Cup Liner Closure Per Pulsation Cycle on Bovine Mastitis

S. Y. REITSMA,[1] E. J. CANT,[2] R. J. GRINDAL, D. R. WESTGARTH, and A. J. BRAMLEY
National Institute for Research in Dairying
Shinfield, Reading, England RG2 9AT

ABSTRACT

Measurements of teat end expansion and contraction times from step changes in pressure suggest that teat ends require a minimal duration of liner closure for response. Effect of duration of liner closure per pulsation cycle on susceptibility of the udder to infection was tested. Four durations of liner closure (liner more than half closed) were applied: zero, .17, .34, and .51 s per pulsation cycle. For the latter three treatments, duration of the liner more than half open was .66 s per pulsation cycle, resulting in pulsation rates of 72.3, 60.0, and 51.3 pulsations per min. Four groups, each of 10 British Friesian cows, were in a 4-wk experiment. High bacterial exposure of all teats was ensured by dipping them before and after each milking in a suspension of *Streptococcus agalactiae* and *Streptococcus dysgalactiae*. Numbers of quarters becoming infected per treatment group were 20, 11, 4, and 5. This result represents both a significant inverse linear and quadratic relationship between proportion of quarters becoming infected and duration of liner closure. We conclude that a sufficient duration of liner closure, i.e., one-third of a second or more, per pulsation cycle contributes to reducing risk of new mammary gland infections.

INTRODUCTION

Mastitis-causing bacteria generally enter the mammary gland by penetration through its streak canal. Two milking machine mechanisms influencing streak canal penetration have been reported for the two chambered milking machine teat cup. The impact mechanism (8, 9, 10) has been investigated most widely and is understood better. The second mechanism has been proposed by Bramley et al. (2), who found that stopping pulsation of the liner in the conventional double chambered teat cup increased the rate of new infections. They included in their experiments several pulsation rates and ratios which did not influence infection rate, but all resulted in a duration of liner closure (liner more than half closed) of at least one-third second.

Reitsma and Scott (6) reported measurements of teat end expansion and contraction as a consequence of pressure changes applied as a step input uniformly applied to the whole teat inserted into a teat chamber. Teat ends require a mean .20 s to contract after intermittent exposure to milking vacuum of about 50 kPa. Times required for teat end contraction, defined as fall times, varied significantly for cow within group. The mean low and mean high fall times for four vacuums between 25 and 50 kPa were .08 and .52 s. The fall times for teat end contraction are interpreted as a key for selecting the time of liner closure during each pulsation cycle and as an indication of the time needed to relieve tissue straining and blood congestion, particularly at the teat end (5). A main hypothesis proposed from this research is: shorter durations of liner closure per pulsation cycle generally provide insufficient time for teat ends to respond to and, therefore, insufficient relief. This may result in teat ends being more strained at the end of milking making penetration by bacteria more likely. Viscoelastic behavior of teat end tissue has been demonstrated by Stettler (7) and McDonald (4), whereas Balthazar and Scott (1) reported extensively on stress-strain relationships for teat wall tissue.

The objective of our experiment was to determine if duration of liner closure (liner more than half closed) per pulsation cycle affects new infection rate under conditions of high bacterial challenge.

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[1] Agricultural Engineering Department, University of Manitoba, Winnipeg, Canada R3T 2N2.

[2] Johnson Matthey & Co. Ltd., Sonning Common, Oxfordshire, England.

MATERIALS AND METHODS

Experimental milkings were in a six-stall double (2 × 3) tandem milking parlor. The vacuum pump capacity was approximately 990 liters of free air per min for the six milking units and always exceeded demand. Each milking point was provided with a weigh jar. Each milking unit consisted of an Alfa-Laval[3] claw (No. 24933) with the air vent sealed. Teat cups were standard Vaccar[4] assemblies (No. 12–03–02) modified as follows. Each sight glass was provided with a .51 mm diameter air vent and the bore increased to 7.94 mm, equal to that of the short milk tube. The sight glass is a standard transparent nipple connecting the tail piece of the liner to the short milk tube. Vaccar silicone liners (No. 10–01–21) were used because a silicone liner maintains a constant tension better than liners of other elastomers, which is important in maintaining the selected experimental conditions of definite durations of liner closure. A teflon disc, with a diameter of 25.40 mm and a thickness of 2.38 mm, was located inside each liner against the sight glass. Each disc had three slots with a 6.35 mm width around a 12.70 mm closed center. The total open area of the three slots was approximately 1.5 times the open cross sectional area of the short milk tube. Each disc was kept readily in place by the contracted liner near the sight glass and acted as a deflector shield to prevent teat end impacts (3). The total mass of each milking unit was about 2 kg. Pulsation was provided by a Fullwood[5] electromagnetic pulsator (No. 43000). An eight-position switch was located at each milking point to provide the four liner ratio treatments selected for this experiment. Four different outputs were provided by a pulsator control box with digital electronics allowing current on- and off-times in multiples of cs. These four outputs provided electrical signals resulting in durations of the liner more than half closed of 0, .17, .34, and .51 s. Examples of recordings of pulsation chamber vacuum and of liner wall position, as a function of time, for the three treatments with a pulsating liner, are in Figure 1. The duration of the liner more than half open was .66 s. The duration of .66 s was selected as it represents a commonly practiced method and assures the same duration of exposure to vacuum with the liner more than half open. Consequently, pulsation rates were 72.3, 60.0, and 51.3 pulsations per min. Liner wall movement was measured with a rectilinear displacement transducer[6] (Type PD 11) positioned perpendicularly to the plane of liner closure at 38 mm from the end of the teat cup shell near the sight glass. That particular location was selected as the approximate center position between the sight glass and an artificial teat (length 86 mm) inserted into the liner representing an average teat length. Changes in pulsation chamber vacuum were measured with an Endevco[7] pressure transducer (Model 8503–40). Both signals were recorded by a light beam oscillographic Bell and Howell[8] recorder (Model 5–124). The recordings in Figure 1B are fairly common for milking systems having 60 pulsations per min and a wide pulsation ratio. Liner ratios were checked after experiment finish and were unchanged. During the experiment pulsation tubings between pulsator and teat cup frequently were checked for possible leakage by a hand operated vacuum pump.

Forty British Friesian cows of various lactation ages and free from intramammary infections were used. The mean daily milk yield was 22.94 kg/cow with a range of 12 to 35 kg. The mean whole udder peak milk flow rate was 3.67 kg/min per cow with a range of 2.1 to 5.4 kg/min per cow. They were ranked on whole udder peak milk flow rates and then allocated randomly to the four treatments. Initially, a larger group was used to determine if all cows comfortably could be milked with any of the four selected treatments. Some cows were excluded because of udder infection or failure to milk adequately without liner pulsation.

The four treatments were applied for 4 wk. No bacterial suspension was applied the 1st wk. All teats were dipped the last 3 wk before and after milking in a suspension containing approximately 5×10^8 cfu/ml of about equal numbers of *Streptococcus agalactiae* 221/22

[3] Alfa-Laval Co. Ltd., Cwmbran, Wales.

[4] Vaccar Ltd., Winchester, Hampshire, England.

[5] Fullwood and Bland Ltd., Ellesmere, Shropshire, England.

[6] Pye Ether Ltd., Stevenage, Herts, England.

[7] Endevco (UK Branch), Royston, England.

[8] Bell and Howell Ltd., Basingstoke, Hants., England.

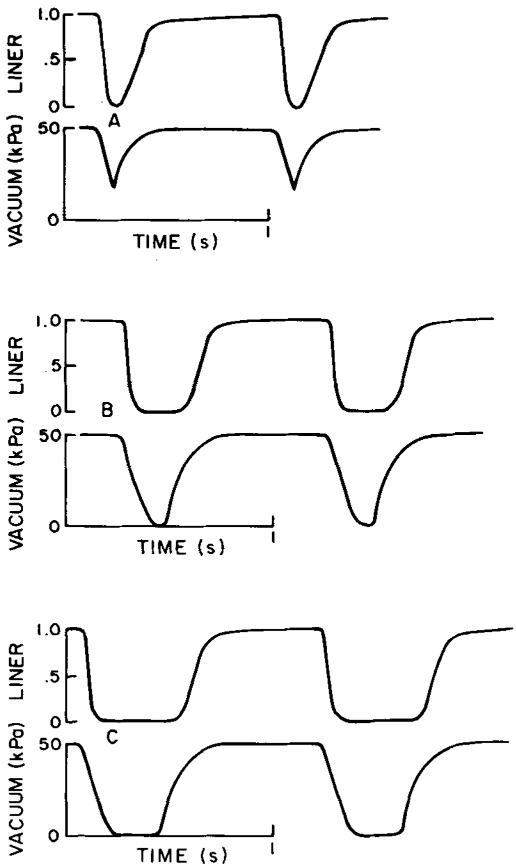

Figure 1. Three sets (A, B, and C) of recordings of pulsation chamber vacuum level (kPa) and liner wall position (1: open, 0: closed), illustrating each of the three durations of liner closure (liner more than half closed) for the treatments with a pulsating liner. Durations of liner closure for sets A, B, and C are .17, .34, and .51 s.

and *S. dysgalactiae* CE 127. These suspensions were prepared as described by Thiel et al. (9).

Milking started at 0600 and 1430 h. A foremilk cup was used for all quarters, the udder washed with warm water, dried with a paper towel, and bacterial suspension was applied. Shortly thereafter the milking unit was attached to the udder. After milk flow ceased, the milking vacuum supply to the milking unit first was closed off, allowing the unit to fall away from the udder into the operator's hand. Aseptic foremilk samples were taken from all quarters on two occasions both before and after exposure to bacteria. Samples also were taken during the experiment from quarters showing signs of clinical mastitis. If mastitis was severe, antibiotic therapy was administered immediately, but for less severe cases results of the examination of milk sample were awaited. All samples were examined for gross abnormalities, the presence of bacteria, and their somatic cell content.

Most infections were accompanied by clinical signs of mastitis, but in other cases the presence of a pathogen in two samples, collected on separate occasions, and an elevated cell count were regarded as indicative of infection. Quarters were no longer dipped in the bacterial suspension after administration of antibiotic therapy.

RESULTS

Infection results of the four durations of liner closure are in Table 1. The no-pulsation treatment resulted in half the quarters and 90% of the cows becoming infected; as the duration of liner closure increased, the risk of infection fell.

Streptococcus agalactiae was isolated from 30 of the 40 infected quarters. *Streptococcus dysgalactiae* was also in 4 of these. The remaining 10 infected quarters were from *S. dysgalactiae*. There was no indication that the distribution of these two types of pathogens interacted with experimental treatment.

Quarter results were examined by analysis of variance of scores whereby a score of zero was assigned to each quarter which remained uninfected and a score of one assigned to each quarter which became infected during the 3-wk of high bacterial exposure. The analysis, by the GLM (general linear models) procedure of the Statistical Analysis System (SAS),[9] demonstrated highly significant differences ($P<.001$) between treatment means.

Partitioning the treatment effect into linear, quadratic, and cubic components showed that the response relationship between proportion of quarters infected, P_Q, and the duration of liner closure, d(s), may be represented by a quadratic equation over the range of d (Figure

[9]SAS Institute Inc., SAS Circle, Box 8000, Cary NC 27511.

TABLE 1. Effect of duration of liner closure on the proportion of quarters and of cows which became infected.

Liner more than half closed (s)	Ratio of infected to total number of quarters	Proportion of quarters which became infected			Proportion of cows which became infected
		Front	Rear	Mean	
0	20/40	.400	.600	.500	.90
.17[a]	11/40	.250	.300	.275	.70
.34[a]	4/40	.050	.150	.100	.40
.51[a]	5/39[b]	.053	.200	.128	.40
		SE of a treatment mean:		±.063 (36 df)	±.147 (36 df)

[a]Liner more than half open for .66 s per pulsation cycle.

[b]One missing record from a quarter developing an infection just before the start of the exposure period.

2A). With each treatment a greater proportion of rear quarters than front quarters became infected (Table 1), and overall, 31% of rear quarters and only 19% of front quarters became infected. The difference is almost significant ($P = .08$).

An analysis of variance of scores also was applied to cow results, score of one to cows which became infected in one or more quarters. Differences between treatment means (Table 1) were almost significant ($P<.06$). Partitioning the treatment effect into linear, quadratic, and cubic components showed that the response of proportion of cows which became infected, P_C, to duration of liner closure, d(s), was significant ($P<.01$). Curvilinearity of the response relation over the range of duration of liner closure was not established with confidence (Figure 2B).

DISCUSSION

The effect of duration of liner closure is more pronounced for quarter scores than cow scores. The main reason for this is that the frequency of multiple quarter infections was higher among the animals milked without pulsation or with the shortest duration of liner closure. The score based on quarters represents, therefore, a better method of detecting treatment differences.

The two treatments with longer durations of liner closure (.34 and .51 s) approximately cover the range for wide to narrow pulsation ratios of commonly supplied milking systems. Both represent in that sense typical field conditions. The proportion of infected quarters on these treatments was of the same magnitude as the mean proportion of the controls in four previous experiments (2).

A main factor besides pulsation influencing liner ratios is large vacuum changes within the liner. That situation was not applicable here mainly because of adequate air admission at each teat cup sight glass.

One of the common tests on milking systems, particularly when mastitis has arisen as a problem, is to make a pulsation chamber vacuum recording. It would be difficult to predict accurately the liner ratio from such a pulsation recording. This is because of the inadequate response performance of many of the instruments (11) and the lack of information on the dynamic response of the liner to pressure changes (5).

Statistical analysis of results suggests a teat position effect ($P = .08$) with rear quarters more easily infected than front quarters. Analysis of dynamic teat end responses has shown that front teat ends expand considerably more ($P<.05$) than rear teat ends, but the teat end fall times do not differ between teat positions (5). Hence, front teat ends contract faster than rear teat ends, and this may account for or contribute to their resistance to infection. Interaction between teat position and treatment effects was not established.

Only one cow in the no-pulsation treatment did not incur any infections, possibly because her teat ends were able to resist exposure conditions which led to the remaining nine animals in the group developing 20 quarter infections. Understanding the mechanism of

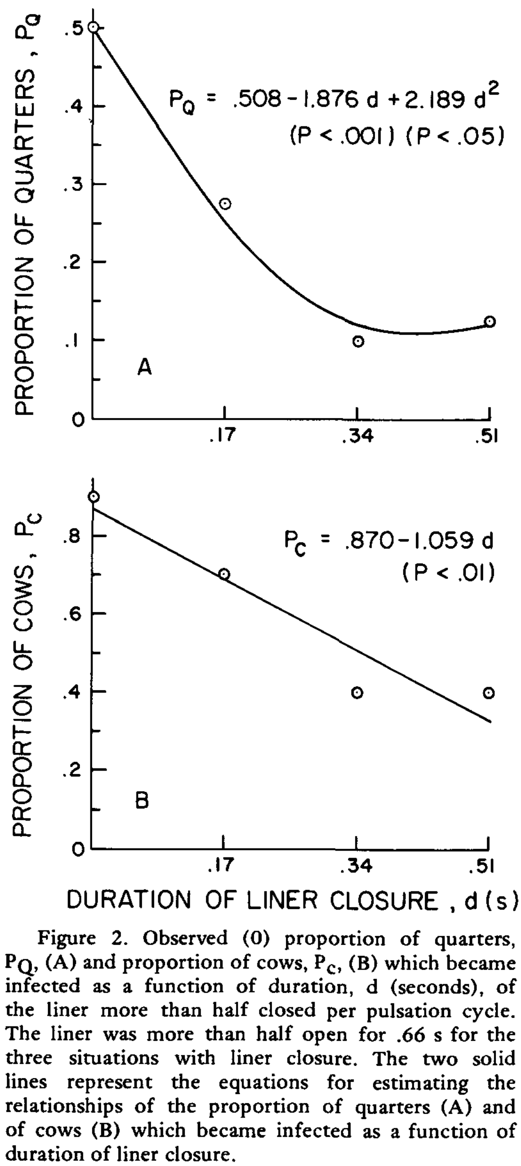

Figure 2. Observed (0) proportion of quarters, P_Q, (A) and proportion of cows, P_C, (B) which became infected as a function of duration, d (seconds), of the liner more than half closed per pulsation cycle. The liner was more than half open for .66 s for the three situations with liner closure. The two solid lines represent the equations for estimating the relationships of the proportion of quarters (A) and of cows (B) which became infected as a function of duration of liner closure.

resistance to infection of teats of some cows and its heritability might be of significance for mastitis control in the future.

Experiments of this type but including measurement of teat end responses to pressure changes will help to explain this infection mechanism. It is unclear from our data whether the bacteria penetrated the teat duct during milking or in the interval between milkings. The earlier studies of Bramley et al. (2) showed that these infections could be prevented by application of a disinfectant teat dip after milking. This suggests that the penetration of the teat duct occurred in the milking interval or required teat orifice colonization. It is possible that application of bacterial suspension to teats before milking is unnecessary, and similar results would have been obtained with contamination applied only after milking.

CONCLUSIONS

Experimental measurement and analysis of effects of four durations of liner closure (0, .17, .34, and .51 s) per pulsation cycle on the occurrence of new infections, under conditions of high bacterial exposure, resulted in the following conclusions. 1) Occurrence of new quarter infections increased considerably with a decrease in duration of liner closure. A duration of liner closure of one-third of a second appeared desirable to reduce the incidence of mastitis. 2) Proportion of quarters becoming infected is a considerably more sensitive criterium for detecting treatment differences than proportion of cows' udders becoming infected. 3) Rear quarters were infected more readily than front quarters. 4) Teat end diameter responses may help to explain why the occurrence of infections differs between quarters and between cows.

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