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Interactions of vacuum, b-phase duration, and liner compression on milk flow rates in dairy cows

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ABSTRACT

Vacuum, b-phase duration, and liner compression are 3 milking machine factors that affect peak milk flow rate; however, extreme values of these factors can also have negative effects on teat tissue health. The main and interactive effects of vacuum, b-phase duration, and liner compression on peak milk flow rate were studied by independently controlling these causal variables over a wide range of settings, using a central composite experimental design (42 to 53 kPa of system vacuum, 220 to 800 ms of b-phase, and residual vacuum for massage of 16 to 30 kPa; corresponding to a liner compression of 8 to 14 kPa). The results of this study indicated that increasing the vacuum and b-phase duration always increased peak milk flow rate (no relative maximum was reached); however, the rate of increase of flow rate decreased as the vacuum and b-phase were increased. Increasing the liner compression also increased peak flow rates, with an increasing effect at greater vacuum. The interaction between vacuum and liner compression and the lack of interaction between b-phase and liner compression indicate that for a corresponding increase in peak milk flow rate, increasing the b-phase produced less teat-end tissue congestion than increasing the vacuum. The effect of milking vacuum on peak milk flow rate was smaller than that reported in previous studies, probably because of the independent adjustment of milking vacuum and liner compression used in this study. The effect of b-phase duration on peak milk flow was also smaller in this study than in previous studies, probably because of the independent adjustment of b-phase and d-phase durations used in this study.
Key words: vacuum, b-phase duration, pulsation, liner compression

INTRODUCTION

For most of the past century, vacuum and the duration of the b-phase of pulsation (as determined by pulsation rate and ratio) have been regarded as the primary machine factors influencing peak milk flow rate (**PMF**) and milking speed. It is widely accepted that both PMF and milking speed increase as milking vacuum is raised (Smith and Petersen, 1946; Baxter et al., 1950; Stewart and Schultz, 1958; Clough, 1972; Rasmussen and Madsen, 2000; Spencer and Rogers, 2004; Spencer et al., 2007). Peak milk flow rate and milking speed increased as the b-phase of pulsation was lengthened to approximately 600 ms (Clough, 1972; Spencer et al., 2007), but decreased in one study when the b-phase was increased further to 750 ms (Clough, 1972).

Increasing the vacuum and the b-phase (by changing either pulsation rate or ratio) increased teat congestion, as reflected by changes in teat wall thickness after milking, measured by using skin-fold calipers (Hamann, 1990; Hamann et al., 1993) or ultrasonic images (Neijenhuis et al., 2001; Gleeson et al., 2004; Vinitchaikul and Suriyasathaporn, 2007). Hamann and Mein (1996) concluded that a d-phase duration of at least 150 ms was enough to relieve congestion and that greater d-phase durations resulted in little further decrease in congestion or increase in milk flow rate. A limitation of most of these pulsation studies is that the method used to lengthen the b-phase usually resulted in a concomitant shortening of the d-phase of pulsation.

Machine-induced congestion of teat tissues is relieved if liner compression (**LC**) during the d-phase of the pulsation cycle is of adequate magnitude and duration (Williams and Mein, 1982). Congestion that develops in the liner-open phase during the peak milk flow-rate period of milking but that is not relieved by the available LC will have a direct influence on PMF (Williams and Mein, 1982). Liner compression is a function of the physical dimensions of the liner, primarily wall thickness; the material properties of the liner, which change with time and use; liner mounting tension; and the pressure

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difference across the liner during the d-phase, which is affected by the milking vacuum (Mein et al., 2003). In a typical milking system, increasing the milking vacuum will also increase LC. One previous study that used independent adjustment of LC and milking vacuum reported that increased LC resulted in increased PMF (Williams et al., 1981); however, the b-phase was far in excess of the practical duration for milking and was not varied. When LC is adjusted either by changing the liner type or by the experimental method described by Williams et al. (1981), the b-phase and d-phase are also changed. Mein et al. (1987) predicted that LC equal to the mean arterial pressure of approximately 12 kPa would be sufficient to relieve congestion and that additional LC would provide no additional benefit. In a later review, Mein et al. (2003) postulated that the LC required to relieve congestion was related to the milking vacuum, with greater LC being required at greater vacuum.

The role of LC in reducing teat tissue congestion during milking, and thereby influencing PMF and milking speed, has become clearer in the last 20 yr (Thomas et al., 1991; Davis et al., 2000; Gleeson et al., 2004; Mein et al., 2004). However, such studies have typically used the same liner at different vacuums or different liners at the same vacuum. These methods lack independent control of milking vacuum and LC and therefore cannot separate the main effects of individual variables or correctly assess the interaction between these 2 important aspects of milking.

The primary objective of this study was to quantify the milking machine effects of vacuum, b-phase, and LC on milk flow rates to gain a better understanding of the physiological responses of teat tissues to machine milking. This study was designed to control these 3 causal variables independently over a broad range so that both main and interaction effects could be estimated. Our primary interest was in the effects of vacuum, b-phase, and LC on PMF, but we also measured average milk flow rate (**AMF**) over the entire milking to gain further insight into the influence of these causal variables during the low-flow period of milking.

MATERIALS AND METHODS

Milking Facilities and Procedures

This experiment was performed at the University of Wisconsin-Madison, low-level milkline, milking parlor. Treatments were applied during the p.m. milkings, allowing the a.m. milkings to reduce any possible carryover effects. The milking parlor operators used consistent preparation procedures for the duration of the experiment that consisted of predip application, manual forestripping, cleaning the udder with cloth towels, and then unit attachment. The resulting total premilking tactile stimulation was approximately 25 s, with a preparation lag time (time from the end of preparation to the attachment of the first teat cup) of approximately 60 s. Researchers were present at each p.m. milking to ensure consistency of the preparation routine, accuracy of data collection, and accuracy of cow identification.

Automatic cluster removers were set at a flow threshold of 0.6 kg/min and a detachment delay of 3 s. Milk flow meters were installed at each milking stall during the test period milkings (Lactocorder, WMB AG, Balgach, Switzerland). The a.m. milkings used the preexperimental milking system vacuum (44.5 kPa), pulsation rate (60 cycles/min), and pulsation ratio (60:40; a-phase = 161 ms, b-phase = 443 ms, c-phase = 173 ms, d-phase = 222 ms). The PMF data used for this analysis were as reported by the milk flow meter and were defined as the maximum observed milk flow rate from all 4 teats in any 11.2-s interval during the milking. Average milk flow rate was taken as the total milk yield per milking divided by the total machine-on time.

Milking system vacuum was adjusted at the regulator and confirmed with a calibrated vacuum gauge. Wet tests were performed with an artificial udder to determine the relationship between the system vacuum and average claw vacuum at various water flow rates. This relationship was linear and is described by the equation

$$\text{Average claw vacuum (kPa)} = [0.97 \times \text{milking system vacuum (kPa)}] - [1.03 \times \text{milk flow rate (kg/min)}].$$

Pulsation rate and ratio were adjusted so that the b-phase corresponded to the treatment value while the d-phase was maintained at 250 ms for all treatments. The duration of the d-phase was chosen to be substantially longer than the International Organization for Standardization (Geneva, Switzerland) minimum of 150 ms, with the intent that the d-phase would not be a limiting factor in congestive relief for any of the treatments. The a-phase and c-phase of pulsation averaged 161 and 173 ms, respectively, and showed minimal changes across the range of experimental treatments. These changes were taken into account when adjusting the pulsation rate and ratio for each treatment, and the b-phase and d-phase durations were confirmed with a dry test of pulsation before each treatment.

New liners were installed in the milking parlor 3 d before the beginning of the experiment. The liners used