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Estimating teat canal cross-sectional area to determine the effects of teat-end and mouthpiece chamber vacuum on teat congestion

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ABSTRACT

The primary objective of this experiment was to assess the effect of mouthpiece chamber vacuum on teat-end congestion. The secondary objective was to assess the interactive effects of mouthpiece chamber vacuum with teat-end vacuum and pulsation setting on teat-end congestion. The influence of system vacuum, pulsation settings, mouthpiece chamber vacuum, and teat-end vacuum on teat-end congestion were tested in a 2 × 2 factorial design. The low-risk conditions for teat-end congestion (TEL) were 40 kPa system vacuum (Vs) and 400-ms pulsation b-phase. The high-risk conditions for teat-end congestion (TEH) were 49 kPa Vs and 700-ms b-phase. The low-risk condition for teat-barrel congestion (TBL) was created by venting the liner mouthpiece chamber to atmosphere. In the high-risk condition for teat-barrel congestion (TBH) the mouthpiece chamber was connected to short milk tube vacuum. Eight cows (32 quarters) were used in the experiment conducted during 0400 h milkings. All cows received all treatments over the entire experimental period. Teatcups were removed after 150 s for all treatments to standardize the exposure period. Calculated teat canal cross-sectional area (CA) was used to assess congestion of teat tissue. The main effect of the teat-end treatment was a reduction in CA of 9.9% between TEL and TEH conditions, for both levels of teat-barrel congestion risk. The main effect of the teat-barrel treatment was remarkably similar, with a decrease of 9.7% in CA between TBL and TBH conditions for both levels of teat-end congestion risk. No interaction between treatments was detected, hence the main effects are additive. The most aggressive of the 4 treatment combinations (TEH plus TBH) had a CA estimate 20% smaller than for the most gentle treatment combination (TEL plus TBL). The conditions designed to impair circulation in the teat barrel also had a deleterious effect on circulation at the teat end. This experiment highlights the importance of elevated mouthpiece chamber vacuum on teat-end congestion and resultant decreases in CA.
Key words: teat end, teat barrel, peak milk flow, vacuum, pulsation, congestion

INTRODUCTION

During milking the teat end can become swollen through congestion, which is an accumulation of fluid in the circulatory pathway, or a combination of congestion and edema. Edema is the accumulation of excess body fluid in the tissue interstitial space and is normally preceded by congestion (Reinemann, 2012). A single papillary artery supplies the teat; it courses through the middle layer of the teat wall and runs vertically and distal from the teat base. This artery passes inside a plexus of larger veins and the teat base venous ring. A superficial network of smaller arteries supplies the teat skin. Veins of the teat are large and thick walled, and they contain numerous valves directed toward the teat base. Arteries and veins are connected via a network of small capillaries throughout the skin and parenchymal tissue (Habel, 1989; Konig et al., 2004). Milk flows through the teat canal during the milking phase of pulsation because of the pressure difference across the teat end. Circulatory fluid also accumulates in the teat end at an increased rate due to reduced pressure within the tissues of the teat end. The function of pulsation in the teatcup is to provide liner compression to the teat end, which assists the return of blood and lymph flow through the veins and lymph ducts during milking (Williams et al., 1981; Hamann and Mein, 1996). No liner compression is applied to the teat-barrel wall through this process, and venous and lymphatic return is not assisted in the teat wall at the

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level of the barrel except through forces applied at the teat end (Reinemann, 2012).

Teat-end congestion will reduce milk flow rate (**MFR**; Williams and Mein, 1986) and hence reduce milking speed. Congestion has also been associated with increased IMI (Mein et al., 1983; Zecconi et al., 1996). Teat-end congestion has previously been estimated in various ways, including use of a cutimeter (Hamann and Mein, 1988; Zecconi et al., 1992; Ambord and Bruckmaier, 2010), electronic calipers (Hamann et al., 1993), ultrasound (Gleeson et al., 2004; Bade et al., 2009), and optical methods (Zwertvaegher et al., 2013). Teat-end congestion can also be indirectly estimated by changes in the teat canal cross-sectional area (**CA**). During milking, the pressure difference created across the teat wall and teat end due to vacuum expands the teat end radially but within the confines of the open liner, while not exceeding the elastic limit of the epidermis and underlying connective tissue (Williams and Mein, 1982). The CA can be used as a biologically relevant indicator of congestion because the teat skin has limited ability to expand because of the forces generated by milking vacuum and congestion fluids compared with the inner parenchymal tissue. Once the teat skin has reached its elastic limit, parenchymal tissue in the teat-end region can only swell because of congestion through a decrease in the teat canal lumen CA (Williams and Mein, 1982). The CA can be estimated by the application of the Bernoulli theorem for liquid flow through a rough pipe from direct measurement of MFR, the total time milk is flowing during each pulsation cycle, and the pressure difference across the teat canal (Upton et al., 2016a).

Past research has demonstrated that an increase in teat-end vacuum can induce teat-end congestion (Hamann and Mein, 1988; Gleeson et al., 2004). Lengthening the b-phase duration has also been demonstrated to increase teat-end congestion when vacuum and liner compression are kept constant (Bade et al., 2009).

Teat-barrel congestion risk is driven by mouthpiece chamber vacuum (**Vmpc**), which is in turn affected by teat dimensions relative to liner dimensions (Gomez et al., 2011; Ronningen and Postma, 2012). Increased Vmpc has been shown to be associated with the formation of congestion in the teat barrel (Rasmussen, 1997; Reinemann et al., 2013). Because of the anatomical configuration of the teat circulatory system, particularly the venous system, we postulate that the pressure difference due to Vmpc that congests the teat-barrel might also congest the teat-end tissue through increased capillary pressure or constrictions in the venous pathways at any point in the teat barrel.

The primary objective of this experiment was to assess the effect of Vmpc on teat-end congestion. The secondary objective was to assess the interactive effects of Vmpc with teat-end vacuum and pulsation setting on teat-end congestion.

MATERIALS AND METHODS

A 2 × 2 factorial experimental design was used with treatment conditions designed for low or high risk of teat-end congestion (**TEL** and **TEH**, respectively) and low or high risk of teat-barrel congestion (**TBL** and **TBH**, respectively) as described in Table 1. A system vacuum of 49 kPa was chosen for the TEH condition to ensure a high probability of teat-end congestion. A triangular liner was used with the mouthpiece chamber (**MPC**) connected to either the short milk tube (**SMT**) or atmosphere. This liner had a measured mouthpiece diameter of 21 mm, mouthpiece depth of 35 mm, mid-barrel diameter of 21 mm, and an overpressure (**OP**) of 9.8 kPa, indicating midrange liner compression. Eight cows (32 quarters) were used in the experiment, which was conducted during 0400 h milkings under IACUC-approved animal use protocol A005167. Cows were randomly assigned to the 4 treatments, with all cows receiving all treatments (2 × 2 factor combinations) over 4 d with the exception of one cow removed from the experiment because of behavior problems on d 3 and 4.

The experiment was carried out at the University of Wisconsin-Madison Dairy Cattle Center using a recently designed and constructed quarter milking analysis device (Mi4; Upton et al., 2016b). The design of Mi4 components for harvesting milk from a single quarter is described in Figure 1. Vacuum levels in the pulsation system, all short milk tubes (**Vsmt**), Vmpc, and milk weight harvested for each quarter were recorded at 1,000 Hz. The long milk hose connecting each teatcup to the milk collection tube was 16-mm internal diameter to reduce vacuum differences between Vsmt and system vacuum (**Vs**) due to friction. Teat lengths were recorded with a transparent ruler modified for this purpose before unit attachment on the first day of the experiment. All cows were prepared for milking with a teat disinfectant and wiped with a clean cloth before attachment after about 1 min according to the standard operating procedure of the parlor. Teatcups were applied for 150 s for all treatments to standardize the exposure period. This treatment time was chosen so that all quarters had a high probability of staying in the peak milk-flow period for the duration of each treatment allowing for assessment of teat-end congestion under the 4 treatment combinations. The d-phase duration for all treatments was 200 ms with the a-phase and c-phase each approximately 100 ms; the duration of the b-phase was held at either 400 or 700 ms by means of a purpose-built pulsator controller. This con-