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The influence of different milking settings on the measured teat load caused by a collapsing liner

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ABSTRACT

Milking machine settings such as the machine vacuum, pulsation rate, and pulsation ratio influence teat tissue and teat condition, but there remains a lack of knowledge about the teat-liner interface and the pressure applied to the teat tissue by the teat cup liner during milking. The aim of the present study was to determine the influence of different milking settings on the teat-liner interface with the help of a pressure-indicating film. The Extreme Low Prescale film by Fujifilm and a hollow artificial teat made of silicone were used to measure the influence of different machine vacuum levels (30 kPa, 40 kPa, 50 kPa), different pulsation rates (40 cycles min^{-1}, 60 cycles min^{-1}, 80 cycles min^{-1}), and different pulsation ratios (60:40, 65:35, 70:30) on the teat load caused by the collapsing liner. The response surface methodology with a central composite design was used to plan the experiment. The experiment was performed with a conventional milking cluster equipped with round silicone liners. The average pressure (AP), the maximum pressure (MP), and the load (L) were used to analyse the influence of different milking settings. Analysis of covariance was used to estimate the differences between measuring areas, machine vacuum levels, pulsation rates, and pulsation ratios. Machine vacuum levels, pulsation rates, and pulsation ratios had a significant influence on the measured teat load caused by liner collapse; the higher the machine vacuum and the pulsation rate, the higher the measured values of AP, MP, and L. MP values decreased with an increase of the pulsation ratio. The pulsation ratio affected L significantly depending on the machine vacuum. The liner applied more pressure to the end of the teat compared with the whole teat barrel. In conclusion, the results of the present investigation show that different adjustments to the machine vacuum, the pulsation rate, and the pulsation ratio can significantly influence the pressure applied to the whole teat by a collapsing liner.

1. Introduction

Machine milking significantly affects teat tissue parameters (Gleeson et al., 2002) and can worsen teat condition (Mein et al., 2001; Mir et al., 2015). Several methods, such as teat scoring (Neijenhuis et al., 2000; Mein et al., 2001; Rose-Meierhöfer et al., 2014), ultrasound measurements (Neijenhuis et al., 2001; Gleeson et al., 2004; Parilova et al., 2011), calculating the Touch Point (TP), the Over-Pressure (OP), and the Liner Compression (LC) (Mein and Reinemann, 2009), and direct pressure measurements (Davis et al., 2001; Tol et al., 2010; Leonardi et al., 2015), are available to assess the influence of machine milking on teat tissue and teat condition directly after milking as well as over a longer period of time.

The settings of machine vacuum, pulsation rate, and pulsation ratio affect teat tissue and teat condition. Excessive machine vacuum leads to cracks in the epithelium of the teat tissue (Williams and Mein, 1985). Hamann and Mein (1988) investigated the thickness of the teat end in response to different vacuum settings (30 kPa, 50 kPa, and 70 kPa) and found that the teat-end thickness increased as the vacuum level increased; tissue stiffness increased as well (Hamann and Mein, 1988). The comparison between a machine vacuum at 30 kPa, 40 kPa, and 50 kPa showed significant differences in teat thickness (Hamann et al., 1993), and a comparison of two different vacuum settings showed that milking at a lower level resulted in less colour changes of the teat and less cornification of the teat orifice (Ebendorff and Ziesack, 1991). According to Ryšánek et al. (2001), a high vacuum correlated significantly (correlation coefficient of 0.50) with the formation of teat-end hyperkeratosis, and reducing the machine vacuum decreased the risk of hyperkeratosis (Neijenhuis et al., 2005). Reinemann et al. (2001) did not find a significant correlation between machine vacuum level

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and teat-end callosity, but they found a tendency towards more teats with worse scores and fewer teats with improving conditions with a vacuum of 50 kPa compared to 42 kPa. Parilova et al. (2011) tested the influence of two different vacuum levels (39 kPa and 45 kPa) on the traits teat length, teat diameter at the base, teat diameter at the middle, teat canal length, teat end width, teat wall thickness, and teat cistern width. The authors found a longer teat and teat canal, a narrower teat diameter at the base and at the middle, a wider teat and teat cistern, and a thicker teat wall with a higher machine vacuum. A machine vacuum level of 42 kPa resulted in increased teat wall thickness and a decrease in teat cistern diameter compared with a machine vacuum of 50 kPa (Besier and Bruckmaier, 2016). In contrast, a low machine vacuum level extended the milking duration and worsened the teat end condition (Reid and Johnson, 2003).

Different pulsation settings can influence both teat condition and teat tissue condition. Grindal (1988) found that extending the suction phase led to an increase in teat lesions and subcutaneous bleedings. Hansen et al. (2006) investigated the influence of different pulsation rates and pulsation ratios on teat thickness and found significant differences between 'fast' (22–55 cycles min^{-1}, 66–81% suction phase) and 'slow' (47 cycles min^{-1}, 43% suction phase) treatments; the 'fast' treatment resulted in an increase in teat thickness. A comparison of seven d-phase duration levels (50 ms, 100 ms, 150 ms, 175 ms, 225 ms, 250 ms, and 300 ms) resulted in a significant reduction in the estimated cross-sectional area of the teat canal at d-phase durations of 50 and 100 ms (Upton et al., 2016). Bluemel et al. (2016) found that an extended c-phase during the pulsation cycle decreased the total vacuum per cycle by 1 kPa and increased the opening and closing duration of the liner, so the authors concluded that an extended c-phase indicated gentler milking. In contrast, Gleeson et al. (2004) observed no negative effect on teat tissue by widening the pulsation ratio, and Ferneborg and Svennersten-Sjaunja (2015) detected no negative effects of different pulsation ratios on teat-end hyperkeratosis or teat tissue thickness as well. A quarter individual milking system for conventional milking parlours (MultiLactor®) with a machine vacuum of 37 kPa, a sequential pulsation at a rate of 60 min^{-1} and a pulsation ratio of 65:35 resulted in better teat colour scores after milking compared with a conventional milking system with a machine vacuum of 40 kPa, a pulsation rate of 60 min^{-1}, and a pulsation ratio of 60:40 (Rose-Meierhöfer et al., 2014).

Machine vacuum and pulsation settings influence TP, OP, and LC values as well. TP was found to increase with a higher machine vacuum (Spencer et al., 2007), and according to Mein et al. (2003), OP increased with increasing liner vacuum. These authors found a slight increase in OP as the pulsation c-phase was shortened as well, so adjusting the pulsation settings to a ratio of 65:35 and a rate of 60 cycles min^{-1} might reduce the effects of OP. A higher claw vacuum was found to create a larger difference in pressure across the wall of the collapsed liner and result in a higher LC (Mein and Reinemann, 2009). Both OP and LC were found to increase as the vacuum level of the individual liners increased (Reinemann and Mein, 2011).

The aim of the present investigation was to determine the influence of different milking settings on the pressure applied to the whole teat by a collapsing liner using a pressure-indicating film and a hollow artificial teat made of silicone.

2. Materials and methods

2.1. Study design

Following Bade et al. (2009), the response surface methodology (RSM) with the central composite design (CCD) was used to design the experiment. Machine vacuum, pulsation rate, and pulsation ratio were chosen as independent variables, and the three levels of each variable were as follows: the machine vacuum was adjusted at 30 kPa, 40 kPa, and 50 kPa; the pulsation rates were 40 min^{-1}, 60 min^{-1}, and 80 min^{-1}; and the pulsation ratios were 60:40, 65:35, and 70:30. The different levels of each variable were coded to conform with the CCD (Table 1).

Table 1
Coded and uncoded levels for the independent variables used in the response surface methodology.

Independent variable	Coded level		
	−1	0	+1
Milking system vacuum (kPa)	30	40	50
Pulsation rate (cycles min^{-1})	40	60	80
Pulsation ratio	60:40	65:35	70:30

Table 2
The 15 combinations of machine vacuum, pulsation rate, and pulsation ratio detected with the central composite design.

Machine vacuum (kPa)	Pulsation rate (cycles/min^{-1})	Pulsation ratio
30	40	60:40
30	40	70:30
30	60	65:35
30	80	60:40
30	80	70:30
40	40	65:35
40	60	60:40
40	60	65:35
40	60	70:30
40	80	65:35
50	40	60:40
50	40	70:30
50	60	65:35
50	80	60:40
50	80	70:30

The CCD design resulted in 15 unique combinations (Table 2) of machine vacuum, pulsation rate, and pulsation ratio. The central point (40 kPa, 60 cycles min^{-1}, 65:35) was repeated ten times, and five replicates were performed for each of the other combinations for a total of 80 measurements.

2.2. Data collection

Data were collected using an experimental setup similar to Demba et al. (2016). The Extreme Low film type (Prescale by Fujifilm; KAGER Industrieprodukte GmbH, Dietzenbach, Germany) and an artificial teat made of silicone were used to investigate the influence of different milking settings on the teat load caused by a collapsing liner. The pressure range of the film was 0.05–0.2 MPa. The teat had a length and a mean diameter of 56 mm and 21 mm, respectively and was hollow with a teat wall thickness of 4.5 mm. According to the manufacturer, the silicone rubber had a Shore A hardness of 25, a density of 1.16 g cm^{-3} at a temperature of 23 °C, a tensile strength of 5.00 N mm^{-2}, an ultimate elongation of 350%, a tear resistance of more than 20 N mm^{-1}, and a linear shrinkage of 0.5%. The experiment was carried out in the experimental milking parlour of the Leibniz Institute for Agricultural Engineering and Bioeconomy e.V. (ATB). A conventional milking cluster (Surge, GEA Group AG, Düsseldorf, Germany) equipped with round silicone liners (IQPro, GEA Group AG, Düsseldorf, Germany) was used, and each liner had a shaft diameter of 24 mm, a mouthpiece diameter of 21 mm, and a head diameter of 58 mm. All measurements were performed using the same teat cup; the other teat cups were closed with plugs (Fig. 1). The pressure-indicating film was cut into pieces (35 mm × 45 mm), all of which were attached with tape to the same position on the teat. The artificial teat was then inserted in the teat cup so that the collapsed liner and the sides of the pressure-indicating film were pressed together, and milking was simulated for 1 min. The pieces of film were then analysed with FDP-8010E software by Fujifilm (Prescale by Fujifilm; KAGER Industrieprodukte GmbH,