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Infrared Thermography and Ultrasonography to Indirectly Monitor the Influence of Liner Type and Overmilking on Teat Tissue Recovery

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Paulrud CO, Clausen S, Andersen PE, Rasmussen MD: Infrared thermography and ultrasonography to indirectly monitor the influence of liner type and overmilking on teat tissue recovery. Acta vet. scand. 2005, 46, 137-147. – Eight Danish Holstein cows were milked with a 1-mm thick specially designed soft liner on their right rear teat and a standard liner mounted under extra high tension on their left rear teat. Four of the animals were overmilked for 5 min. Rear teats were subjected to ultrasound examination on the first day and to infrared thermography on the second day. Teats were submersed in ethanol 20 min post-milking on the second day. Ultrasonography measurements showed that teat canal length increased by 30-41% during milking. Twenty minutes after milking, teats milked with modified standard liners still had elongated teat canals while teats milked with the soft liner were normalized. Overmilking tended to increase teat wall thickness. Approximately 80% of variability in teat canal length, from before teat preparation to after milking, could be explained by changes during teat preparation. Thermography indicated a general drop in teat temperature during teat preparation. Teat temperature increased during milking and continued to increase until the ethanol challenge induced a significant drop. Temperatures approached pre-challenge rather than pre-milking temperatures within 10 minutes after challenge. Teat temperatures were dependent on type of liner. Mid-teat temperatures post-challenge relative to pre-teat preparation were dependent on overmilking. Thermography and ultrasound were considered useful methods to indirectly and non invasively evaluate teat tissue integrity.

Dairy cow; milking, teat integrity, thermography, ultrasound.

Introduction

Several scientific publications deal with the acute response of teat tissue to machine milking (*McDonald* 1975, *Schultze & Bright* 1983, *Hamann & Dück* 1984, *O'Shea* 1987, *Persson* 1991, *Bramley et al.* 1992). *Hamann* (1989) pointed out the various degrees of altered teat tissue fluid-dynamics as a significant reason why milking may have a negative effect upon teat defence mechanisms. There is general agreement that machine milking can result in congestion and oedema of the teat tissue especially at the teat end and also influence teat diameter, penetrability of the teat canal, and defence mechanisms.

The functional effect of impaired teat fluid circulation may be divided into firstly, effects concerning teat canal closure and passage of pathogens, and secondly, possible effects on the immunological defence mechanisms concerning antigenic detection and initiation of immunological responses.

Hillerton et al. (2002a) found overmilking to be associated with poor teat condition. Furthermore, avoidance of overmilking was pointed out to be essential in order to accomplish good parlour performance and acceptable cow comfort (*Hillerton et al.* 2002b). *Natzke et al.* (1982) on the other hand reported no apparent effect on external teat end condition but an increased rate of new infections among overmilked cows and concluded that the higher new infection risk was associated with increased rates of cross infections, presumably due to increased unit-on time. This hypothesis was supported by *Mein et al.* (1986) who found an increased new infection rate when pulsation failed especially in conjunction with overmilking and that overmilking increased new infection rate mainly or only when it was associated with pulsation failure.

The vacuum applied during the milking phase of machine milking disturbs the naturally occurring teat contractions and results in accumulation of fluid in the teat tissue. These contractions normally remove interstitial fluids from the teat via the lymphatic vessels. During the massage phase, however, teats will be massaged by a compressive load that facilitates venous flow and removal of interstitial fluid (*IDF* 1987). During periods when the milk flow is low or none, the existing removal of blood and interstitial fluids may be insufficient and congestions and oedema may develop (*IDF* 1987). *Jankus & Baumann* (1986) examined the blood flow through the distal parts of the teat and found that the blood flow through the teat canal epithelium and the papillated portion of the stratum papillare were 4 times that of equivalent structures of the mucosal (Furstenberg's) rosette. They suggested two factors that may account for the high blood flow: 1) The secretion of antimicrobial substances, and/or 2) The requirement for cellular replacement due to epithelial *stratum corneum* losses during milking.

A number of methods to measure teat tissue condition have been introduced. Ultrasonography of teats in order to measure teat congestions may be the most frequently used method (*Worstorff et al.* 1986, *Spencer et al.* 1996). Other methods used to study the microcirculation and integrity of teats include Laser doppler flowmetry (*Persson* 1991, *Hamann et al.* 1994), teat consistency by cutimeter or caliper measurements (*Hamann & Mein* 1988), radiographic methods (*Pier et al.* 1956, *McDonald* 1975, *Mein et al.* 1973) and different methods of measuring teat surface temperature (*Hamann & Dück* 1984, *Hamann* 1985 & 1988, *Eichel* 1992, *Ordolff* 2000).

Ultrasonography permits a visualisation of body structures by recording the echoes of continuous pulses of ultrasonic (1-10 MHz in diagnostic ultrasonography) waves directed into the tissue. Those frequencies can be transmitted only through liquids and solids and consequently teat ultrasonography is performed through a contact gel or by immersing the teat into water.

Skin temperature can be used in order to estimate tissue integrity since it reflects the underlying circulation and tissue metabolism. In order to avoid any skin contact and to increase the study area and time efficiency, infrared thermography has been adopted to study temperature patterns of udder and teat skin (*Hamann & Dück* 1984). Thermography is based on the principle of the Stefan-Boltzmann law whereby the energy flux emitted by a surface is related to its temperature. Thermography focuses, collects and transforms the infrared range of the electromagnetic spectrum that is emitted from any body in a heat dependent fashion. Thermography furthermore images a pictorial summary of the heat gradients generated and can thereby visualise the thermal patterns of the skin resulting in useful mapping of the underlying circulation. The generally high degree of thermal symmetry in healthy animals makes it

possible to detect subtle, abnormal asymmetries. Generally, teat integrity may be assessed either by comparing the actual temperature or relative temperature between adjacent teats or comparing the teat's ability for circulatory response to a certain challenge.
The objectives of this study were: First, to study the influence of certain liner characteristics and overmilking on teat recovery by indirectly monitoring circulatory impairments of teat tissue via infrared thermography and ultrasound scanning. Second, to compare responses measured by infrared thermography and ultrasound scanning.

Materials and methods

Eight Danish Holstein cows from the herd at the Research Centre Foulum were milked experimentally in a combined group and split udder design. Cows were diagnosed as being free of clinical mastitis for at least 4 weeks before the start of the experiment. In addition, rear teats had similar size and shape and deposited milk in a similar fashion (time span). In order to perform and compare both infrared thermography and ultrasound scannings, the same individuals were milked identically during two consecutive afternoon milkings.
Cows were housed in a tie-stall, manually stimulated for 30 seconds with a moistened cloth and manually foremilked. Cows were machine-milked with a high pipeline milking system, a SAC Uniflow milking unit, a milk line vacuum of 48 kPa, 60 c/min and a 60:40 pulsation ratio. On their right rear teat, the cows were milked with a 1-mm thick, soft, experimental liner (soft liner) with a mouthpiece only 5 mm high. On their left rear teat, the cows were milked with an SAC (S A Christensen, Kolding, Denmark) No:15012 liner (extended liner) mounted under extra high tension in a 12-mm extended standard shell, resulting in a 30-mm mouthpiece height. Both front teats were milked with standard mounted SAC-15012 conventional liners. Only data from rear teats were recorded. Cows were randomly divided into two groups.
Four animals were milked with the automatic cluster remover set at a threshold of 300 g/min while the remaining four animals were milked excessively for 5 min to simulate overmilking.
On the first day of experimental treatment, the rear teats were subjected to ultrasound examination pre-teat preparation (PRP), post-teat preparation (POP), immediately after milking (AM), and 20 minutes post-milking (AM+). Ultrasonographic scans were carried out with an ALOKA Echo Camera model SSD-500 mounted with a 7.5 MHz ultrasound probe by submerging teats in a water-filled (35°C) plastic cup as described by Spencer et al. (1996). Images were stored on a video recorder.
On the second day, the animals were milked as on day one. Thermographic images (Raytheon, "Radiance PM", focal array camera, 256×256 pixels and a sensitivity of about 0.025°C) of the rear teats were taken pre-teat preparation (PRP), after teat preparation (POP), immediately after milking (AM), and 20 minutes after milking (AM+). Then the teats were challenged by a quick submersion in ethanol. The teats were thereby cooled as a consequence of ethanol evaporating and changing function of state from liquid to gas. Excessive cooling of the teat tip was avoided by removing a drop of ethanol at the teat tip with a cloth. A series of final thermographic images were taken 2, 5, and 10 minutes after challenge (C+2, C+5 and C+10, respectively). Temperatures were recovered by processing the thermographic images in AmberTherm software (Amber, USA) Temperatures were recorded at the centre of the teat tip, at the mid-teat, and at the centre of the teat base. The ambient temperature at time of thermography was 19ºC.
Ultrasound measures of the thickness of the teat cistern wall, teat cistern diameter and the teat

canal length as well as temperatures derived from the thermographic pictures at teat tip, mid-teat and teat base were compared between treatments. Results from ultrasound were compared to those from thermography.

Data analysis

The absolute and relative temperatures were analysed by the following model using the statistical procedure PROC MIXED (SAS, 1999):

Y = LINER + OVERMILKING + TIME + POSITION + LINER × OVERMILKING + LINER × TIME + OVERMILKING × TIME

· Random effects: COWNR × OVERMILKING
· Repeated: LINER(COWNR)

LINER was the effect of the two different milking machine liners. OVERMILKING was the effect of overmilking for 5 minutes or not. TIME was whether data was collected pre-preparation, after preparation, 0 and 20 minutes after milking, and 2, 5 and 10 minutes after challenge. POSITION was the effect of location at the teat: base, mid and teat tip. Ultrasound measures of the thickness of the teat cistern wall, teat cistern diameter, and teat canal length were analysed using the same model but leaving out the term POSITION. Data are presented as Least Squares Means.

Results

Teat skin temperature

Teat skin temperatures were dependent on the position on the teat and the time of measurement but not on overmilking, Table 1. Teat skin temperature decreased significantly from teat base to mid-teat and from mid-teat to teat tip ($p<0.001$), Table 2. After milking, overall teat temperatures were significantly dependent on the type of liner (AM $p<0.05$ and AM+ $p<0.001$). Even though differences in teat temperature between liners were small (table 2), milking with the soft liner resulted in colder teats than milking with the extended liner. Also after the ethanol challenge, the overall teat temperature was significantly dependent on the type of liner (C+2: $p<0.05$; C+5: $p<0.01$; and C+10: $p<0.001$) but independent of overmilking. The most obvious response to different liners was recorded 10 minutes post-challenge where temperatures at both teat tip, mid-teat and teat base were significantly lower on teats milked with soft liners, Table 2.

Table 1. Least Squares Means of temperatures of teats milked with extended and soft liner, respectively, and overmilked or not. Temperatures were taken from pre-teat preparation, after preparation, immediately after milking, 20 minutes after milking, and 2, 5, and 10 minutes after an ethanol challenge.

Liner	Extended Liner		Soft Liner		Levels of Significance		
Overmilking	- (n=12)	+ (n=12)	- (n=12)	+ (n=12)	Position	Liner	Overmilk
Pre-Preparation	34.4	33.8	33.8	33.8	***		
Post-Preparation	32.5	32.7	32.3	32.1	***		
Milking +0 min.	35.2	34.9	34.3	34.2	***	*	
Milking+20 min.	35.3	35.6	34.6	34.9	***	***	
Challenge +2 min.	33.0	32.9	32.0	32.4	**	*	
Challenge +5 min.	34.7	34.7	34.1	34.1	***	**	
Challenge +10 min.	34.8	35.6	34.1	34.8	***	***	

Statistical differences are designated with *, **, or *** for 5, 1, and 0.1 percent significance levels, respectively.

Table 2. Least Squares means of teat temperatures of teats milked with extended and soft liners, respectively. Temperatures were taken from pre-teat preparation, after preparation, immediately after milking, 20 minutes after milking, and 2, 5, and 10 minutes after an ethanol challenge.

Liner Teat Position	Extended Liner			Soft Liner			Levels of Significance		
	Base (n=8)	Mid (n=8)	Tip (n=8)	Base (n=8)	Mid (n=8)	Tip (n=8)	Base	Mid	Tip
Pre-teat preparation	35.2	34.1	33.1	35.0	33.7	32.7			
Post-teat preparation	33.7	32.7	31.4	33.3	32.2	31.1			
Milking +0	35.4	35.9	33.8	35.0	35.1	32.6			
Milking +20	36.0	35.6	34.7	35.6	34.8	33.8		*	
Challenge +2	33.3	33.7	31.9	32.6	32.6	31.4		**	
Challenge +5	35.5	34.8	34.1	34.9	34.2	33.3		*	*
Challenge +10	36.1	35.3	34.3	35.2	34.5	33.6	***	***	*

Statistical differences between temperatures at three positions of the teats as a result of different type of liner are designated with *, **, or *** for 5, 1, and 0.1 percent significance levels, respectively.

Relative temperatures

There was a general drop in teat temperature of about 1.5ºC from pre- to post-teat preparation ($p<0.001$), but this drop was independent of position at the teat ($p=0.76$), Table 3. When comparing temperatures after milking with pre-teat preparation, an effect of position was evident ($p<0.01$). Preparation of the teat affected teat temperature evenly while milking affected teat temperature differently at different areas of the teat.

No effect of liner or overmilking was established on the temperatures post-milking in relation to pre-teat preparation. At the middle, overmilked teats were 1.1ºC and 1.7ºC warmer 5 and 10 minutes post-challenge, respectively ($p<0.05$ and $p<0.01$, respectively) than pre-teat preparation while mid-teats that were not overmilked were only <0.1ºC and 0.3ºC warmer than pre-teat preparation, respectively. Ten minutes after challenge, the overall teat temperature and teat base temperature in relation to pre-teat preparation were significantly dependent on type of liner ($p<0.01$ and $p<0.05$, respectively), Table 3. Ten minutes after challenge, the overall teat temperature in relation to pre-teat preparation tended to be higher among overmilked teats than among the other teats (1.4ºC and 0.4ºC, respectively, $p=0.06$).

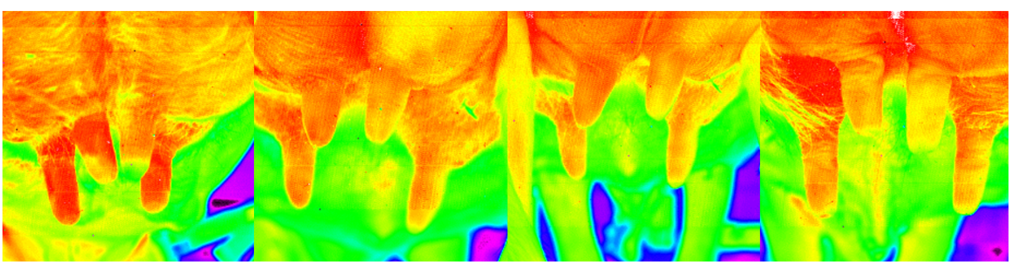

Figure 1. Infrared thermography of four different udders taken between hind legs immediately after milking. Right rear quarters were milked with a soft experimental liner and left rear quarters were milked with a standard liner mounted in an extended shell.

Table 3. Least Squares Means of teat temperatures in relation to temperatures pre-teat preparation measured at base, mid, and tip of teats milked with an extended liner and soft liner, respectively. Temperatures were measured after preparation, immediately after milking, 20 minutes after milking, and 2, 5, and 10 minutes after an ethanol challenge, respectively.

Liner Teat Position	Extended Liner				Soft Liner			
	Base (n=8)	Mid (n=8)	Tip (n=8)	Overall Mean	Base (n=8)	Mid (n=8)	Tip (n=8)	Overall Mean
Post-Preparation	-1.64	-1.41	-1.45	-1.50	-1.58	-1.45	-1.74	-1.59
After Milking	0.75	1.84	0.75	0.92	-0.13	1.40	-0.04	0.41
Milking +20	1.60	1.48	0.88	1.32	1.13	1.15	0.59	0.95
Challenge +2	-1.12	-0.45	-1.90	-1.16	-1.31	-1.24	-2.40	-1.65
Challenge +5	1.00	0.65	0.11	0.59	0.58	0.50	-0.15	0.31
Challenge +10	1.29[a]	1.18	0.89	1.12[x]	0.91[b]	0.80	0.19	0.63[y]

[ab]Numbers with different letters are significantly different ($p<0.05$)
[xy]Numbers with different letters are significantly different ($p<0.01$)

Ultrasound measurements of teat dimensions
Teat diameter, teat wall thickness and teat canal length were significantly dependent upon time ($p<0.001$), Table 4. After milking, no statistical differences were found among treatments. Overmilking tended to increase teat wall thickness after milking ($p=0.066$). Generally, after milking, the teats seemed to have a slightly smaller diameter, a somewhat thicker teat cistern wall, and a longer teat canal, Table 4. Teat canal length 20 minutes after milking in relation to immediately after milking differed significantly between liners ($p<0.01$).

Relations between IR- and US-measures
The change in teat tip temperatures from pre-teat preparation to 10 minutes after challenge was positively correlated with the change in teat canal length from pre-teat preparation to after milking ($p<0.05$ and $R^2=0.26$). Likewise, the change in overall teat temperature correlated positively with the change in teat canal length ($p<0.05$ and $R^2=0.12$).
The change in teat canal length during teat preparation was positively correlated with temperature changes from pre-teat preparation to 0 and 20 minutes after milking ($p<0.001$, $R^2=0.80$ and $p<0.001$, $R^2=0.32$, respectively). The change in teat wall thickness during teat preparation was positively correlated with temperature changes from pre-teat preparation to 20 minutes after milking ($p<0.001$, $R^2=0.31$).

Discussion
Thermal changes during preparation
During manual udder preparation, including pre-stripping and wet cleaning, teat temperature dropped approximately 1.5ºC. This drop in temperature was even throughout the teat surface. Hamann & Dück (1984) reported an average decrease in teat temperature of 0.8ºC after pre-stripping, dry cleaning and manually massage of the teat for 30 seconds before milking. *Hamann & Dück* (1984) hypothesized that prior to manipulation teat veins are filled with blood in order to fill the volume of the teat sinus and reach an occlusion. Then manual stimulation initiates removal of blood from teat veins in order to open the occlusion between udder and teat sinus and to increase the volume of the teat sinus. Due to reduced blood volume, the teat wall gets colder and the teat temperature may decrease.
A second explanation would be that teat stimu-

Table 4. Least Squares Means of teat diameter, teat cistern wall thickness, and teat canal length of teats milked with extended and soft liners and overmilked for 5 minutes or not. Measurements were done by ultrasound and given as absolute values or relative to pre-teat preparation (mm). Dimensions are given from pre-teat preparation (PRP), after preparation (POP), immediately after milking (AM), and 20 minutes after milking (AM+).

Liner	Extended liner		Soft liner		
Overmilking	-	+	-	+	Level of sign.
Absolute values					
PRP	21.6	22.0	20.4	21.8	
POP	21.4	23.2	20.8	22.8	
AM	19.2	20.8	19.3	19.3	
AM+	20.3	20.3	20.0	19.7	
Relative values					
POP-PRP	-0.2	1.2	0.4	1.0	
AM-PRP	-2.4	-1.2	-1.1	-2.5	
AM+-PRP	-1.3	-1.7	-0.4	-2.1	
AM+-AM	1.1	-0.5	0.7	0.4	
Teat cistern wall					
Absolute values					
PRP	5.5	6.0	5.2	6.7	
POP	5.4	6.1	5.3	6.8	
AM	6.5	9.3	6.5	8.1	+
AM+	7.3	7.9	6.9	8.0	
Relative values					
POP-PRP	-0.1	0.1	0.1	0.1	
AM-PRP	1.0	3.3	1.3	1.4	
AM+-PRP	1.8	1.9	1.7	1.3	
AM+-AM	0.8	-1.4	0.4	-0.1	
Teat canal length					
Absolute values					
PRP	11.4	11.2	11.2	12.9	
POP	11.9	11.4	12.5	14.3	**
AM	14.8	14.4	15.8	16.9	*
AM+	13.6	15.0	12.0	13.2	
Relative values					
POP-PRP	0.5	0.2	1.3	1.4	
AM-PRP	3.4	3.2	4.6	4.0	
AM+-PRP	2.2	3.8	0.8	0.3	
AM+-AM	-1.2	0.6	-3.8	-3.7	**

Statistical differences between teat properties as a result of different type of liner designated with * or ** and as a result of overmilking are designated with + or ++ for 5 and 1 percent significance levels, respectively.

lation will decrease the sympathetic tone of the mammary gland (*Lefcourt* 1982a) resulting in increased blood flow but, however, also a decreased rate and amplitude of teat and teat sphincter muscle contraction (*Lefcourt* 1982b) resulting in decreased blood flow in the teat tissue.

However, skin blood flow is also under the control of the sympathetic nervous system, and noradrenergic sympathetic neurons control the blood flow through the teats. During preparation of teats, local extrinsic stimuli as tactile and thermal sensations are registered by mechano- and thermal receptors in the teat skin. Responses evoked by such stimuli are alpha-adrenergic (mediated by adrenergic vasoconstrictor nerves) and include contraction or relaxation of vascular muscles. A third possibility for teats to be colder after preparation may therefore be activation of the autonomous nervous system and an increase in sympathetic tone (alpha-adrenergic response), causing haemodynamic changes including arterioles to contract and arteriovenous anastomoses to close (peripheral vasoconstriction of the local cutaneous vascular plexus). All in all, this results in restricted skin blood flow in the teats and decreased heat dissipation to the surroundings.

Influence of milking on teat temperature

While preparation of the teat affected teat temperature approximately evenly throughout the teat surface, milking on the other hand affected teat temperature differently at different areas of the teat. The absolute temperatures of the teats after milking and 20 min after milking were significantly higher of teats milked with the extended than with the soft liner. When comparing temperatures post-milking with temperatures pre-preparation, an effect of position was evident ($p<0.01$).

During milking, mid-teat temperature increased markedly while both teat base and teat tip temperatures tended to increase less or even slightly decrease with the extended and soft liner, respectively. A decrease in tone as seen during milking causes arterioles and arteriovenous anastomoses to open, the blood flow to markedly increase, and therefore the convective heat loss from the skin to increase.

Hamann & Dück (1984) found that the teat apex and the areas around the annular folds demonstrated the most marked changes in skin temperatures from pre-preparation to post-milking. Teat apex had increased temperatures and teat base had slightly decreased temperatures compared to values pre-preparation.

When comparing those results to the extended liner in the present trial, we can confirm that teat tip temperature increased during milking relative to pre-preparation. Conflicting results concerning teat base may be explained by differences in the technical parameters of the milking systems or differences in liner design.

Isaksson & Lind (1994) proposed three circumstances that influenced the temperature conditions during milking. First, the milk flow through the teat lumen, second, the enclosure of the teat in the teatcup, and third, the reactions in the cutaneous vascular plexus. These authors pointed out that heat gain is largely balanced by heat loss to the blood stream. If so, one may conclude that the larger the difference is between pre-milking and post-milking temperatures, and the longer those differences exist, the more impairments on teat circulation the process of milking has caused.

As mentioned, the present data do not directly measure the blood flow per se but rather the resulting temperature. One may, however, speculate whether the blood flow post-milking is influenced by the requirements for cellular replacement due to epithelial *stratum corneum* losses during milking and the secretion of antimicrobial substances, as proposed by *Jankus*

& Baumann (1986). Even though this hypothesis seems reasonable, the magnitude of such influence on the present results should be non-significant.

Influence of challenge on teat temperature

The purpose of introducing a thermal challenge was to investigate whether treatment had any effect on the autonomic nervous system and the vascular system's ability to perform a 'somato sympathetic response'. Immediately after challenge, teat temperature had dropped approximately 2.5ºC on average in relation to before challenge and 1.4ºC in relation to pre-preparation. This drop in temperature may mainly be ascribed to the rapid evaporation of ethanol (entropy change) where energy is absorbed from the teat surface. The relative drop in temperature was highest among teats milked with the soft liner (NS). Temperatures measured 5 and 10 min. after challenge seem to approach the values measured 20 minutes post-milking rather than pre-preparation temperatures. This may indicate that machine milking induces long lasting alterations in teat fluid dynamics. Neijenhuis et al. (2001) suggested that the process of teat recovery, as determined by ultrasonographic scanning, lasts >8 h.

Irrespective of type of liner, overmilked mid-teats were 1.1ºC and 1.7ºC warmer at 5 and 10 min. after challenge, respectively, than before preparation while mid-teats that were not overmilked were only <0.1ºC and 0.3ºC warmer, respectively, than before teat preparation. Overmilking therefore seems to result in prolonged teat recovery time and perhaps reduced ability to perform a 'somato sympathetic response' to the challenge. Temperatures relative to pre-preparation of teats milked with the extended liner at 10 min. after challenge were about twice that of teats milked with the soft liner. Therefore one may conclude that teats milked by soft liners have shorter recovery time and perhaps increased ability to perform the 'somato sympathetic response' than did teats milked with the extended liner. Results from Rasmussen et al. (in progress) comparing differences of teat condition post-milking confirm a significant difference between the very same two liners as used in the present experiment. They found that milking with the experimental liner reduced ringing of the teat base, teat condition scores after milking, and anatomical changes associated with milking studied by ultrasound. The mentioned parameters are all associated with circulatory impairments of the teat, as is the reduced ability to perform a relevant 'somato sympathetic response'. Consequently teats with consistent differences in teat temperatures compared to pre-milking may have reduced ability to regulate the blood flow through the cutaneous vascular plexus.

Ultrasonography

The teat diameter decreased independently of treatment during milking but was 6-13% smaller after milking. Teat canal length increased by 30-41% during milking. Twenty minutes after milking, teats milked with the extended liner still had elongated teat canals while teats milked with the soft liner had teat canal lengths non-significantly different from pre-teat preparation. This stands in contrast to Neijenhuis et al. (2000) who claim an increase in teat diameter of about 12% and an increase of only about 10% in teat canal lengths from pre-teat preparation to after milking. Teat wall thickness did not respond to treatment but did generally increase by 20-50% during milking. This result confirms the results of Neijenhuis et al. (2001) who found an average increase of 34% in teat wall thickness from pre-preparation to after milking.

Our results show that approximately 80% and 32% of the variability in the changes of teat canal length from pre-teat preparation to 0 and

20 minutes after milking, respectively, could be explained by changes occurring during teat preparation. If teat preparation and milking are performed as in the present experiment, it is possible, with fair accuracy, to estimate teat canal elongation from before teat preparation to immediately after milking and 20 minutes after milking. Since the change in teat canal length from immediately after to 20 min. after milking was significantly dependent on type of liner, one may suspect that the impact of the type of liner may have reduced the linear relationship of elongation during teat preparation and that occurring during milking.

Implications and conclusions

Somewhat surprisingly, the actual teat temperature seems to be more dependent on type of liner than the temperature relative to pre-teat preparation. Therefore, pre-teat preparation temperatures may possibly be left out when comparing liner impact on teats.

Thermography can be a very useful tool to evaluate, estimate and differentiate short and longer-term tissue reactions to machine milking. Our results stress the importance of teat measuring position and the liner specific tissue alterations.

Milking-induced changes of both teat canal length and teat wall thickness could be predicted by changes during teat preparation but still be dependent on type of liner. Consequently, teats vary in sensitivity or level of response.

Despite somewhat conflicting results, our findings support the suggestion by Neijenhuis et al. (2001) that ultrasound measurement of teat parameters is a useful tool for studying changes in teat properties caused by milking.

The present work did not fully clarify how ultrasonographically assessed teat tissue parameters correspond to thermografically estimated teat temperatures even though some interactions were claimed. Further research may take us closer to the obviously complicated interplay between milking-induced intercellular fluid alterations, circulatory impairments, and teat defence mechanisms.

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Sammendrag

Infrarød termografi og ultralydsskanning til indirekte måling af maskinmalkningens påvirkning af pattekonditionen.

Otte danske SDM køer blev malket med et 1-mm tyndt specialfremstillet pattegummi på højre bagpatte og med et almindeligt pattegummi monteret i et forlænget hylster på venstre bagpatte. Fire køer blev overmalket i 5 min. Pattedimensioner blev målt ved hjælp af ultralyd den første dag og pattehudstemperaturen blev målt med infrarød termografi på andendagen. Patterne blev dyppet i alkohol 20 min. efter aftagning af malkesættet. Længden af pattekanalerne blev øget med 30-41% under malkningen og var stadig forlænget 20 minutter efter malkning med det almindelige pattegummi, men ikke med specialpattegummiet. Overmalkning havde tendens til at øge pattevægstykkelsen. Ca. 80% af variationen i pattekanallængden fra før forberedelsen til efter malkning kunne forklares ud fra ændringer under forberedelsen. Pattehudens temperatur faldt under forberedelsen, blev øget under og efter malkningen, men faldt betydeligt efter dypning i alkohol. Ti minutter efter dypningen nærmede hudtemperaturen sig værdier fundet før forberedelsen nærmere end efter malkningen. Hudtemperaturen afhang af anvendt pattegummi. Ændring i hudtemperatur fra før forberedelsen til efter dypning afhang af overmalkningen. Det konkluderes, at ultralydsskanning og infrarød termografi er brugbare non-invasive metoder til evaluering af pattekondition.

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