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Effect of milking on bovine teat tissue as measured by ultrasonography

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The objective of this study was to establish, using an ultrasonography technique, the effect on bovine teat tissue of hand milking, catheter milking and machine milking, pre-milking teat stimulation, over-milking and cow milk yield. The periods required for teat tissue recovery after machine milking were also investigated. The following teat tissue parameters were measured directly before and after milking in a series of six experiments: canal length (CL), teat diameter thickness (TDT), cistern diameter (CD), and teat wall thickness (TWT). Teat length (TL) was measured manually using a calibrated transparent tube into which the teats were placed. Ultrasound scan measurements (mm) are presented as the mean tissue changes (increases or decreases) from the pre-milking values. Machine milking resulted in significant ($P<0.001$) changes in all teat tissue parameters measured. Hand milking ($P<0.001$) and milk withdrawal using a catheter ($P<0.05$) resulted in lower TDT values than machine milking. Pre-milking teat stimulation for 30s increased ($P<0.001$) CD and reduced TWT and CL values as compared to non-stimulated teats. Milk yield (6.4 kg vs. 17.8 kg per milking) had a significant effect ($P<0.01$) on changes in CL, CD and TWT, but did not affect TDT. Over-milking by five and eight minutes did not affect TDT, TWT or CL values, but reduced ($P<0.01$) CD values. The TDT and TL values returned to pre-milking values within 1h of milking. The CD and CL values had not returned to pre-milking values at 5h after milking. Machine milking induced changes in TDT, but teat stimulation, cow milk yield or over-milking did not increase thickness values.

Keywords
Cattle,
Ultrasonography,
Machine milking,
Teat reactions.

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Introduction

Hamann and Mein (1990) suggested that machine milking should not increase or decrease teat thickness by >5%. The IDF machine milking and mastitis group has recommended the use of the 5% limit as a reference, when determining physiological teat reactions induced by the milking process (Hamann and Burvenic, 1994). Calf suckling, and milk removal *via* a catheter inserted in the teat canal are defined as physiological methods for milk removal, which result in decreased teat thickness values. Teat tissue reactions may decrease the efficiency of the teat defense mechanism and lead to increased risk of new infection (Francis, 1981; Hamann and Mein, 1990; Woolford and Phillips, 1978). Zeconni *et al.* (1992) found a non-significant increase in mastitis infection levels associated with teats thickness changes >5%. They concluded that there was a significant association between teat thickness changes and teat duct colonization. Teat duct colonization can be assumed to be a source of new intramammary infection (Du Preez, 1985). Changes in teat thickness can be interpreted as impairment of the local circulatory system of the teat tissue due to congestion or oedema. Therefore, it is necessary to evaluate how machine milking induces changes in the physiological status of teat tissue.

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Hamann, Nipp and Mein (1988) measured changes in teat-end thickness using a cutimeter, which is a spring-loaded or electronic caliper device. In studies Spencer, Griel and Goldberg (1996) concluded that there was more variability in cutimeter measurements than in ultrasonographic measurements. Ultrasonography is a non-invasive technique of measurement and is employed extensively in animal measurements. Banting (1998) used ultrasonography for the examination of the bovine mammary gland for inflammation and fibrotic reactions of the udder. This technique has been used to examine soft tissues and reproductive physiology of sheep, swine and cattle (Griffin and Ginther, 1992; Beal, Perry and Corah, 1991). It has also been used by Spencer *et al.* (1996), Neijenhuis (1999) and Gleeson and O'Callaghan (1998) to measure changes in bovine teat tissue. Ultrasonography allows measurement of a wide range of teat tissue parameters, including canal length, cistern diameter, teat wall thickness and teat diameter thickness. Hamann, Mein and Wetzel (1993), using the cutimeter method, showed that pre-milking manual udder preparation can change the thickness of the teat barrel. They also concluded that teats return to within ±2% of their pre-milking thickness values within 1 to 2h of milking; however, Neijenhuis (1999), using the ultrasonography technique, suggested that teat recovery took a considerably longer amount of time. The different conclusions may be related to the milking systems used rather than to the measurement methods.

Different levels of over-milking may occur in milking facilities without automatic cluster removers. The effect of different degrees of over-milking on teat tissue reactions has not been established.

This paper describes the use of ultrasonography to measure teat tissue changes and reports the effects of some factors which may influence these changes. The objective of this study was to measure changes in bovine teat tissue as a result of hand milking, catheter milking, pre-milking teat stimulation, machine milking and over-milking. The effect of milk yield on teat tissue changes and the period required for teat tissue recovery after machine milking were also investigated.

Materials and methods

The following equipment was used:

- Personal Computer - Gateway 2000
- Ultrasound Scanner (SDD-500V) - Aloka
- Probe (UST-5561-7.5) - electronic Linear Probe (7MHz)
- Video-card with a pixel resolution of 256x256
- Video-recorder VCR - Mitsubishi
- Mouse or trackball
- Cables (Video in & Video out and RCA-to-RCA cable)
- Connectors (9-pin-to-RCA adapter)
- Femidom condoms
- Lubricating gel
- Plastic ring - 50mm in diameter
- Calibrated transparent tube

Experimental Design

Experiment 1

Experiment 1 measured the effect of two treatments, namely hand milking and machine milking, on teat-tissue changes. Eight cows were milked in a 2x2 Latin Square design experiment with two days per period. Teat-tissue measurements were carried out at the morning (am) milkings on all teats of all cows, both after teat preparation (after teats had been washed and then dried with paper) and directly after cluster removal. Milk yield (kg) was recorded at the am milkings only.

Experiment 2

This half-udder experiment measured the effect on teat-tissue changes of two treatments: namely, milk removal using a teat catheter and machine milking. Eight cows were milked in a 2x2 Latin Square design experiment with two days per period. Catheters were placed in the left teats of cows and the right teats were machine milked. Teat tissue measurements were carried out at am milkings on all teats of all cows, both after teat preparation for milking and directly after milking.

Experiment 3

This half-udder experiment measured the effect on teat-tissue changes of two treatments, namely, pre-milking teat preparation for 30s prior to cluster application and milking without pre-milking stimulation. Teat scan measurements were carried out on all teats of a group of eight cows milked over a two-day period. Teat scan images and teat length measurements were made before teat preparation, both directly after teat preparation (after teats were washed, dried with a paper towel and foremilk drawn over a 30s period per cow) and directly after machine milking.

Experiment 4

Experiment 4 measured the effect of cow milk yield on teat tissue changes. A group of eight cows was milked at 16/8h milking intervals, over a two-day period, and the mean cow milk yields per milking were 17.8kg and 6.4kg for am and (evening) pm, respectively. Teat scan measurements were carried out on the left teats after teat preparation and directly after am and pm milkings.

Experiment 5

Nine cows were milked in a 3x3 Latin Square design experiment, with two days per period, to measure the effect of over-milking on teat tissue changes. Clusters were automatically removed either when milk flow-rate dropped to 0.2kg/min, or after five or eight minutes of over-milking. Teat tissue measurements were carried out on the left teats of all cows both after teat preparation for milking and directly after am milkings. Milking times (s) and milk yields (kg) were also recorded.

Experiment 6

A group of eight cows was milked in Experiment 6 to measure

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FIGURE 1: Teat placed in a condom with the probe in vertical position against the teat wall.

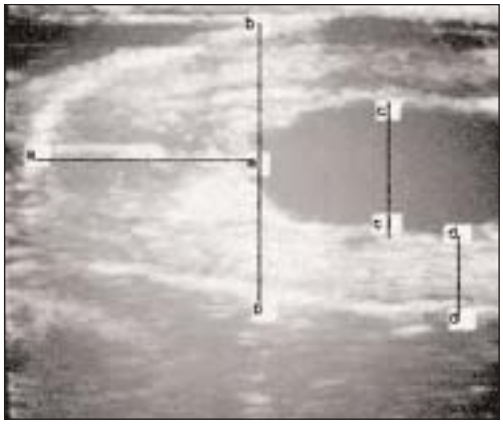

FIGURE 2: Measurement of teat canal length (a), teat diameter (b), cistern diameter (c) and teat wall thickness (d).

FIGURE 3: Calibrated tube in which the teat was placed to measure teat length.

teat tissue recovery during a period of 5h after machine milking. Teat tissue measurements were carried out on the left teats of all cows, directly after teat preparation, directly after milking and at hourly intervals thereafter until and including the fifth hour after milking.

Teat tissue measurement procedures

An Aloka 500v-ultrasound scanner with a 7MHz linear probe was used to measure the cows teats. A Femidom-condom was supported by a plastic ring at the opening; this allowed it to be held in place with one hand, filled with warm water and placed around the cow's teat. A film of lubricating gel was placed on the probe head to improve contact with the Femidom (Figure 1). The probe was manipulated until a clear image of the teat appeared on the screen. When the picture was obtained, the image was frozen on screen. Images of teats were stored on videocassette and these were subsequently measured on screen. A purpose-designed software program was used to automatically record and to file the distance between two points, which were marked with a ball mouse.

The measurements recorded were teat canal length (TCL), teat diameter thickness (TDT), cistern diameter (CD), and teat wall thickness (TWT). TDT was measured across the distal end of the teat canal; CD and TWT measurements were made at 10mm from this point (Figure 2). Measurements of teat tissue are presented as actual figures or as mean changes (increases and decreases) in post-milking values as compared to pre-milking values. Teat length was measured using a calibrated transparent tube into which the teat was placed (Figure 3).

Milking procedure

All cows were milked in a 80° side-by-side milking parlour with a milk lift of 1.2m from the cow standing to a 72mm bore milkline. The machine used for the six experiments had 3.20kg clusters, wide bore tapered liners (31.6mm at the barrel top and 21.0mm at the bottom), a 150ml claw and a simultaneous (4x0) pulsation pattern. Pre-milking teat preparation in all experiments consisted of washing teats with running lukewarm water and drying them with paper towels.

Statistical analyses

Mean teat tissue changes on front and rear teats for all teat measurements were analysed by analysis of variance test using Genstat (Genstat 5 Release 3.2, 1995).

Results

Experiment 1

Machine milking increased (P<0.001) CL, TDT, TWT and TL values and reduced CD as compared to hand milking. Milk yields were similar with hand milking and machine milking (Table 1).

Experiment 2

Machine milking caused greater increases in TDT and TL

TABLE 1: Effect of machine milking, hand milking and milk extraction using a catheter on changes (mm) in teat tissue (data for 16 teats per treatment)

	Experiment 1			Experiment 2		
	Hand milk	Machine milk	s.e.d	Machine milk	Catheter milk	s.e.d
Canal length	1.8[a]	2.8[b]	0.26	2.9	2.7	0.23
Teat diameter	-0.7[a]	0.7[b]	0.39	0.8[a]	-0.0[d]	0.27
Cistern diameter	-5.7[a]	-7.9[b]	1.00	-9.0[a]	-7.6[c]	0.39
Teat wall thickness	1.8[a]	3.4[b]	0.36	4.0[a]	2.7[c]	0.33
Teat length	3.8[a]	7.4[b]	1.26	3.0[a]	-0.1[d]	1.45
Milk yield (kg)	10.86	10.90	0.27	ND	ND	NA

Values, within rows, with different superscripts differ significantly, [ab] (p<0.001), [ac] (p<0.01), [ad] (p<0.05).

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(P<0.05) and in TWT (P<0.01), and caused greater reductions (P<0.01) in CD than milking with the teat catheter (Table 1).

Experiment 3

Pre-milking teat stimulation for 30s increased (P<0.01) CD with a corresponding decrease in TWT as compared to non-prepared teats. CL was reduced (P<0.01) after teat stimulation. There were not differences in TDT and TL between stimulated and non-stimulated teats. Machine milking decreased CD and increased (P<0.001) CL, TDT, CD, TWT and TL as compared to the pre-milking values after teat stimulation (Table 2).

TABLE 2: Effect of teat preparation and machine milking on mean teat tissue measurements (mm) and the effect of cow milk yield on teat tissue changes (data for 16 teats per treatment)

	Experiment 3					Experiment 4		
						Mean yield		
	Dry teat	After teat preparation	s.e.d	After milking	s.e.d	17.8 kg/cow	6.4 kg/cow	s.e.d
Canal length	12.1[c]	11.5[a]	0.17	14.4[b]	0.36	3.1[a]	1.5[b]	0.32
Teat diameter	24.0	23.8[a]	0.13	24.8[b]	0.09	0.9	0.7	0.40
Cistern diameter	11.6[c]	12.7[a]	0.28	5.5[b]	0.67	-8.0[a]	-4.2[b]	0.51
Teat wall thickness	8.3[c]	8.0[a]	0.19	11.4[b]	0.20	3.8[a]	2.4[c]	0.38
Teat length	52.5	52.3[a]	0.91	61.1[b]	0.75	10.6[a]	6.6[b]	0.74

Values, within rows, with different superscripts differ significantly, [ab] (p<0.001), [ac] (p<0.01).

Experiment 4

Teats showed greater increases in CL and TL values (P<0.001), and in TWT values (P<0.01) at the am milkings, at which the mean milk yield was 17.8kg, than at pm milkings at which the mean milk yield was 6.4 kg. The change in CD was greater (P<0.01) after the higher milk yields were harvested (Table 2).

Experiment 5

Cluster removal at five and eight minutes after milk-flow rate had dropped to 0.2kg/min resulted in a reduction (P<0.01) in CD and an increase (P<0.001) in milking time. The CL, TDT, TWT and TL values increased linearly with increasing time to cluster removal but were not significantly different. Time of cluster removal did not affect mean milk yield (Table 3).

TABLE 3: Effect of over-milking for five and eight minutes after milk flow-rate dropped to 0.2 kg/min on teat tissue changes (mm) and milking characteristics (data for 32 teats per treatment) – Experiment 5

Cluster removal	0.2kg/min	0.2kg/min + 5min	0.2kg/min + 8 min	s.e.d
Canal length	2.2	2.8	3.1	0.30
Teat diameter	0.8	1.0	1.0	0.22
Cistern diameter	- 7.7[a]	- 8.5[c]	- 8.8[c]	0.05
Teat wall thickness	3.1	3.7	4.0	0.20
Teat length	6.4	9.3	9.9	2.30
Mean milk yield (kg)	12.3	12.4	12.4	0.93
Milk time (sec)	494[a]	778[c]	978[b]	99

Values, within rows, with different superscripts differ significantly, [ab] (p<0.001), [ac] (p<0.01).

Experiment 6

Machine milking resulted in changes (P<0.001) in all teat tissue parameters measured when compared to pre-milking values. The TDT and TL values had returned to pre-milking values at 1h after milking. The CL and CD values differed (P<0.001) at 4h and (P<0.05) at 5h from the pre-milking values. TWT was higher (P<0.01) for up to 3h and (P<0.05) at 4h before returning to pre-milking values at 5h post-milking (Table 4).

TABLE 4: Teat tissue measurements (mm) before machine milking, directly after milking and at one-hour intervals after milking (data for 16 teats at each interval - Experiment 6

	Before milking	After milking	s.e.d	1 h	s.e.d	2 h	s.e.d	3 h	s.e.d	4 h	s.e.d	5 h	s.e.d
Canal length	11.2[a]	14.3[b]	0.39	13.3[b]	0.52	13.5[b]	0.33	13.3[b]	0.30	13.4[b]	0.26	12.7[d]	0.54
Teat diameter	23.8[a]	24.7[b]	0.21	23.8	0.22	24.1	0.27	24.2	0.26	24.2	0.25	24	0.43
Cistern diameter	13.4[a]	5.3[b]	0.67	6.6[b]	0.53	7.8[b]	0.39	9.1[b]	0.44	9.2[b]	0.49	11.6[d]	0.83
Teat wall thickness	7.5[a]	11.3[b]	0.15	10.3[b]	0.31	9.9[b]	0.27	9.3[c]	0.32	9.5[d]	0.30	8.8	0.46
Teat length	51.1[a]	61.8[b]	1.07	52.8	1.06	52.9	1.01	52.7	1.24	52.8	0.85	52.3	1.39

Values, within rows, with different superscripts differ significantly, [ab] (p<0.001), [ac] (p<0.01), [ad] (p<0.05).

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Discussion

Machine milking resulted in significant changes in teat tissues; this agrees with the findings of Hamann and Mein (1990). Changes in teat tissue were similar with cathether milking and hand milking. The decrease in TDT with hand milking and catheter milking may result from a decrease in the intramammary pressure or the distribution of fluids in the teat end. The change in TDT in machine-milked teats was 3.6% and so was within the range of ±5% suggested by Hamann *et al.* (1995) as a guideline for effectiveness of milking machine settings. Pre-milking teat stimulation for 30s increased CD; this was probably due to enhanced milk letdown. There were corresponding decreases in TWT and CL values. Higher yield per milking resulted in changes in most of the teat parameters measured. Cluster-on times are longer with higher cow milk yield; this may explain some of the changes in the teat parameters measured. Hamann (1990) found a marked increase in TDT in teats which were over-milked for 15 min. However, over-milking of teats for five and eight minutes did not affect changes in mean TDT in Experiment 5. Hamann *et al.* (1993) concluded that vacuum level has a much greater effect than the duration of milking on teat tissue reaction; cluster-on time was 50% longer at the lower vacuum level but there was a significant increase in TDT at the higher vacuum level. This suggests that changes in TDT may be more related to milking machine settings rather than to milking time *per se*. O'Brien (1988) showed that teat sphincter closure takes place within 2h after milking and it is generally assumed that teats have fully recovered to pre-milking values at this time. Complete teat recovery after machine milking did not occur within 5h post milking in the present study; this concurs with the findings of Neijenhuis (1999), namely, that teat recovery may take 6 to 8h. The CL and CD values may not return to their pre-milking values until teat preparation for next milking has been completed. Changes in TDT were apparent after machine milking, but they were not affected by teat stimulation, milk yield or over-milking. Teat thickness changes were within the reference value of ±5% suggested by the IDF for determining physiological teat reactions to the milking process.

The ultrasonic scanning technique gave repeatable results and this was evident in the teat recovery study in Experiment 6. The technique can be used as a research tool to measure the effect of different milking systems on teat tissue reactions.

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