Vacuum level for opening the teat sphincter and the change in the teat end wall thickness in response to the machine milking of indigenous Greek goats

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ABSTRACT: The aim of this paper was to study some of the teat characteristics involved in the milking ability of indigenous Greek goats such as the vacuum level of the milking machine that is required for the opening of the teat canal sphincter and the changes in the teat end wall thickness induced by milking. Thirty-six dams (12 of the first, 12 of the second and 12 of the third and subsequent lactations) were used after weaning (60 ± 5 days). Dams were milked twice a day (8:00 and 18:00 h) for 12 weeks in a milking parlour 1 × 12 side by side of Casse type with 6 milking units and a low milk line and air pipeline. The main functional characteristics of milking machine were: vacuum level 44 kPa, pulsation rate 90 pulsations/min and pulsation ratio 50:50. Every 14 days, during morning and evening milking the vacuum level that was required for the opening of the teat sphincter (VOTS) was measured. The measurement of teat end wall thickness (TEWT) was performed before and after milking. The results of this study showed that during the experimental period the mean VOTS was 23.57 ± 0.36 kPa and decreased significantly as the stage of lactation progressed ($P < 0.001$). The post-milking TEWT was 3.55% higher in comparison with that before milking ($P < 0.01$). A continuous and significant decrease in teat thickness was observed during the lactation stage ($P < 0.001$), which suggests a reaction to intramammary pressure and milk quantity in the udder. The TEWT was affected significantly by the parity ($P < 0.01$). A positive correlation was found between VOTS and TEWT before and after milking (0.4 and 0.36, respectively). It could be said that a lower vacuum level is required for the opening of the teat sphincter of the udder in goats of the indigenous Greek breed. The thicker teat end wall and more resistant sphincter could be less favourable in the machine milking of goats.

Keywords: goat; machine milking; vacuum level; teat thickness; teat sphincter

Milkability of small ruminants depends on animal physiology and udder morphology, on the material and set up of a milking machine and on farmer's experience and technical knowledge (Labussiere, 1988; Katanos et al., 2005). If the above factors work in harmony, then the animals can be milked completely, in the shortest time without any harm of their udder (Marnet et al., 1999; McKusick, 2000; Marnet and McKusick, 2001). From the above parameters the most important are, however, animal physiology and morphology. In the improved breeds of sheep and goats milk ejection is no longer a limiting parameter. So teat characteristics appear to be the most limiting factor for good milkability (Marnet et al., 1999).

The difference in the teat end thickness before and after milking is a parameter to study the response of teat tissue to used parameters or to the liner of machine equipment. Researchers have found a significant relationship between milk emission kinetics parameters and the teat characteristics in goats and cows. In cows, an increase in the teat end wall thickness (TEWT) was observed after milking (Hamann and Mein, 1990). Gleeson et al. (2004) found in cows that vacuum levels of 50 and 40 kPa gave similar changes in the teat tissue after machine milking. In contrast Le Du and Taverna (1989) observed a reduction in TEWT after milking. In the mountainous Greek breed of ewes (Boutsiko), Sinapis et al. (2007) found a slight increase in TEWT (0.63%), while Marnet et al. (1999) and Peris et al. (2003a,b) found thinner teats after milking in Lacaune and Manchega sheep breeds, respectively. The above results suggest an influence of machine settings and especially of too high vacuum level applied to the teat (Hamann et al., 1993) as well as of the teat cup liner design and characteristics (Le Du and Taverna, 1989). The liner design appears to have a bigger effect on the teat tissue changes than pulsation characteristics or vacuum level (Gleeson et al., 2004).

On the other hand, the vacuum level that is required for the opening of the teat sphincter (VOTS) has a significant relationship with the milk flow rate (Marnet et al., 1999). In the Lacaune breed of ewes significant negative relationships were identified between the VOTS (from 25 to 36 kPa) and the mean and maximum milk flow rate and the total milking time. The same results were also reported for goats of Saanen breed by Le Du and Benmederbel (1984), who required VOTS of 34.6 kPa, and for cows by Weiss et al. (2004), who required VOTS around 16 kPa. Sinapis et al. (2007) reported VOTS of 16.59 kPa for a mountainous Greek breed of sheep.

There is limited information concerning the milking ability of goats of indigenous Greek breed and a lack of data on the best machine milking settings, especially on the vacuum level. Our objective was to study the vacuum level for opening the teat sphincter and the change in the teat end wall thickness in response to the machine milking of goats of indigenous Greek breed.

MATERIAL AND METHODS

Experimental design

Thirty-six dams of the indigenous Greek goat breed (12 of the first, 12 of the second and 12 of the third and subsequent lactations) were used in the experiment after a weaning period of 60 ± 5 days. Fourteen dams had twin type birth, while the others twenty-two single type births. The animals were kept indoors all the year round. Their diet consisted o 1 kg of concentrated feed (pellets) administered daily in the milking parlour (0.5 kg at morning milking and 0.5 kg at afternoon milking) and 1.2 kg of lucerne hay given in the stable.

Milking parlour

Dams were milked for 12 weeks in a milking parlour of Casse type with 6 milking units and 12 milking places and a low milk line and air pipeline. The main functional characteristics of milking machines were: vacuum level 44 kPa, pulsation rate 90 pulsations/min and pulsation ratio 50:50. Milking was applied twice daily at 8:00 and 18:00 h and started by the setting of milking teat cups to the udders without any preparation of udders, continued by machine stripping for about 10 s and was finished, after removing the teat cups, by hand stripping of the udder.

Equipment and data acquisition

For all dams, every 2 weeks during both the morning and the afternoon milking the teat end wall thickness (TEWT) was measured with a cutimeter before and after milking (Hamann and Mein, 1990; Marnet et al., 1999). Differences in the thickness before and after the milking were calculated, and the percentage change in post-milking TEWT was calculated as proposed by Hamann et al. (1996b).

In addition, every 2 weeks prior to the morning and evening milking, the vacuum level required for the opening of the teat sphincter (VOTS) without pulsation was determined with a prototype apparatus named "vacuometer". The teat sphincter was considered open when the first drops of milk emerged from the udder.

Milk recording was applied every two weeks (Wednesday afternoon and Thursday morning). Milk fractions at morning and afternoon milking were recorded as follows:
– machine milk MM (ml/day);
– machine stripped milk MSM (ml/day);
– daily milk yield MY = MM + MSM (ml/day).

Table 1. Evolution of milk yield (MY), teat end wall thickness (TEWT) and vacuum for opening the teat sphincter during the experimental period

Variables	Controls					
	1st	2nd	3rd	4th	5th	6th
MY (ml)	1 150 ± 30.5[a]	1 020 ± 28.2[b]	960 ± 28.0[bc]	900 ± 26.4[c]	750 ± 24.6[d]	585 ± 23.2[e]
TEWTb* (mm)	4.98 ± 0.04[a]	4.75 ± 0.04[b]	4.70 ± 0.04[b]	4.5 ± 0.03[c]	4.4 ± 0.03[cd]	4.1 ± 0.03[d]
VOTS (kPa)	27.1 ± 0.40[a]	25.2 ± 0.38[ab]	24.6 ± 0.36[b]	23.4 ± 0.36[bc]	22.2 ± 0.34[c]	21.8 ± 0.33[c]

means with different letters in a row differ significantly
**b* = post-milking TEWT

Each fraction was expressed as a percentage of the daily milk yield.

In 12 dams the milk flow curve was drawn by using a paper tape attached to the milk recording jars. The milk yield level was recorded every 4 s. The milk emission kinetics was measured during successive morning milking in the 2nd, 4th, 6th and 8th week of the experimental period. The average milking rate (ml/s) was calculated as the ratio of machine milk emission (morning MM) to the milking time of emission milk.

Statistical analysis

All the variables measured were compared by ANOVA using the SAS General Linear Model procedure (SAS, 1995). The weeks were treated as different blocks. Multiple mean comparisons were made using Duncan's multiple range tests to classify the effect of parity and type of birth on milking traits, TEWT and VOTS. Pearson's correlation coefficients between different variables of goat milkability were calculated using the CORR procedure.

RESULTS

The vacuum level of the milking machine required for the opening of the teat sphincter (VOTS) was found to be 23.57 kPa (23.38 and 23.76 kPa for the left and right teat, respectively, data not shown). The daily milk yield of goats was 947.2 ml and milk fractions were 769.7 and 177.5 ml for machine milk and machine stripped milk, respectively. The average milking time during the morning milking was found to be 53.5 s and corresponded to a milk quan-

Table 2. Effect of parity on milk partitioning, teat end wall thickness (TEWT) and vacuum level for opening the teat sphincter (VOTS) in goats of the indigenous Greek breed

	Parity (mean ± SE)			Significance
	1st	2nd	3rd >	
Machine milk (ml/day)	738.4 ± 24.2[a]	760.1 ± 27.5[ab]	812.9 ± 28.0[b]	**
Machine stripped milk (ml/day)	169.2 ± 10.4	186 ± 11.7	177.2 ± 12.5	NS
Milk yield (ml/day)	907.6 ± 23.1[a]	946.0 ± 25.2[ab]	990.1 ± 24.5[b]	**
VOTS (kPa)	23.1 ± 0.5	23.4 ± 0.58	24.2 ± 0.58	NS
TEWT (mm)				
Before milking (*b*)	4.10 ± 0.04[a]	4.35 ± 0.03[b]	4.78 ± 0.05[c]	**
After milking (*a*)	4.45 ± 0.04[a]	4.72 ± 0.04[b]	4.85 ± 0.05[b]	**
Milking rate (ml/s)	8.4 ± 0.64	8.4 ± 0.68	8.8 ± 0.69	NS
Milking time (s)	52.1 ± 4.8	54.4 ± 5.2	54.2 ± 4.9	NS

means with different letters in a row differ significantly
NS = not significant; ** $P < 0.01$

tity of 463.8 ml. The average milking rate achieved was 8.5 ml/s (data not shown).

A continuous decrease in VOTS was observed during the milking period ($P < 0.001$, Table 1). On the other hand, the VOTS showed a tendency to increase from 23.1 to 24.2 as the lactation number increased from the first to the third and later lactations (Table 2). The type of birth did not influence the VOTS (Table 3).

The teat end wall thickness (TEWT) increased after milking (4.51 mm before milking and 4.67 mm after milking), presenting a difference of 0.16 mm, which corresponds to a change of 3.55% (data not shown). There was a significant decrease in TEWT during the milking period ($P < 0.01$) from 4.98 mm in the first control to 4.3 in the sixth control (Table 1). The TEWT significantly increased ($P < 0.01$) in the third and later lactations compared to the first or second lactation (Table 2). There were no significant differences between parities in milking rates and milking time. Machine milk and total milk yield were significantly influenced by the parity ($P < 0.01$, Table 2), while machine stripped milk was unaffected.

The TEWT tended to be higher, before and after milking, in the twin type of dams' birth compared to the single type of births either before (4.51 mm versus 4.28 mm) or after milking (4.73 mm versus 4.34 mm), respectively. No significant difference was found in TEWT before and after milking in the two types of birth goats. In machine milk and milk yield a significant superiority was found ($P < 0.01$) for dams that had given birth to and suckled two kids. The milking rates tended to be lower in the group of single type of birth dams and the milking time tended to be higher in the group of twin type of birth goats (Table 3).

The phenotypic correlations between milk fractions and milk flow rate were found to be strong and positive, except for the MSM, which showed negative relationships. No relationships were found between VOTS and machine milk, milk yield, milking rate and milking time. On the contrary, there was a significant positive correlation between VOTS and MSM (Table 4). There was also a positive and significantly high coefficient of correlation between VOTS and TEWT before and after milking (r = +0.40 and +0.36, respectively). It appears that thicker teats demonstrated a slightly higher milking rate. Also, before and after milking thicker teats demonstrated positive and significantly high relationships with MSM (r = 0.55 and 0.40, respectively), with MSM (%) (r = 0.44 and 0.28, respectively) and consequently with milk yield to a lower extent (r = 0.22 and 0.20, respectively).

DISCUSSION

The results of the present paper indicate that a lower vacuum level is required for the opening of the teat sphincter in goats of the indigenous Greek breed (23.57 kPa), compared to the vacuum level required for the French Saanen goats (34.6 kPa, Le Du

Table 3. Effect of the type of birth on milkability, teat end wall thickness (TEWT) and vacuum for opening the teat sphincter (VOTS) in goats of the indigenous Greek breed

	Type of birth (mean ± SE)		Significance
	single	twin	
Machine milk (ml/day)	725.0 ± 24.2[a]	824.1 ± 28.3[b]	**
Machine stripped milk (ml/day)	171.3 ± 10.1	179.4 ± 11.5	NS
Milk yield (ml/day)	896.3 ± 26.5[a]	1 003 ± 27.1[b]	**
VOTS (kPa)	23.8 ± 0.36	23.5 ± 0.35	NS
TEWT (mm)			
Before milking (*b*)	4.28 ± 0.04	4.51 ± 0.05	NS
After milking (*a*)	4.34 ± 0.04	4.73 ± 0.05	NS
Milking rate (ml/s)	8.4 ± 0.4	8.5 ± 0.4	NS
Milking time (s)	53.2 ± 4.9	54.6 ± 5.1	NS

means with different letters in a row differ significantly
NS = not significant; $^{**}P < 0.01$

Table 4. Phenotypic correlations between milk fractions, teat end wall thickness and vacuum for opening the teat sphincter in goats of the indigenous Greek breed

	MM (ml/day)	MSM (ml/day)	MY (ml/day)	MM (%)	MSM (%)	MR (ml/s)	MT (s)	VOTS (kPa)	TEWT (*b*) (mm)	TEWT (*a*) (mm)	Difference (*a–b*) (mm)
MM (ml/day)	1										
MSM (ml/day)	0.31^{**}	1									
MY (ml/day)	0.98^{***}	0.54^{***}	1								
MM (%)	0.50^{***}	-0.50^{***}	0.27^{**}	1							
MSM (%)	-0.50^{***}	0.66^{***}	-0.25^{**}	-0.98^{***}	1						
MR (ml/s)	0.68^{***}	0.30^{***}	0.68^{***}	0.24^{**}	-0.24^{**}	1					
MT (s)	0.65^{***}	0.05	0.55^{***}	0.35^{***}	-0.40^{***}	0.10	1				
VOTS (kPa)	0.04	0.18^{*}	0.07	−0.07	0.05	0.01	0.05	1			
TEWT (*b*) (mm)	0.06	0.55^{***}	0.22^{**}	-0.44^{***}	0.44^{***}	0.10	0.03	0.40^{***}	1		
TEWT (*a*) (mm)	0.10	0.40^{***}	0.20^{**}	-0.28^{**}	0.28^{***}	0.12	0.01	0.36^{***}	0.79^{***}	1	
Difference (*a – b*) (mm)	0.05	-0.20^{*}	−0.04	0.20^{**}	−0.20	0.05	−0.05	0.03	-0.50^{***}	0.24^{**}	1

MM = machine milk; MSM = machine stripped milk; MY = milk yield; MR = milking rate; MT = milking time; VOTS = vacuum for opening the teat sphincter; TEWT = teat end wall thickness, before (*b*) and after (*a*) milking

$^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$

and Benmederbel, 1984). Although a low vacuum level for VOTS was achieved in this study, individual values varied significantly (from 7 to 37 kPa, data not shown). This fact was previously noted by Le Du and Benmederbel (1984) in French Saanen goats where 44–50 kPa was required for 10–15% of the goats. Sinapis et al. (2007) found lower levels of VOTS for the mountainous Greek sheep breed (16.59 kPa). Le Du et al. (1994) found in French Fressian cows that the VOTS was 17.0 kPa for the fore teats and 14.5 kPa for the rear teats.

A continuous decrease was observed in the resistance of the teat sphincter during the milking period. The required VOTS decreased from 27.1 to 21.8 kPa, which means that the resistance of the teat sphincter continuously decreased by the progress of lactation. These findings are in line with the results found for goats (Le Du and Benmederbel, 1984) and for sheep (Sinapis et al., 2007). A decrease was also observed for cows by Larroque et al. (2001).

A large range of the values for VOTS between the ruminant species has been suggested by different authors. Despite this variability that could partly be due to genetics the level of vacuum for machine milking can be reduced at least to the level of 36–38 kPa, depending of the milk line position.

The results of this study showed that the difference in TEWT after and before milking was 0.16 mm (a change of 3.55%). In the mountainous Greek breed of sheep Sinapis et al. (2007) found also a slight increase in TEWT after the milking of ewes (0.63%). In both cases the increase in TEWT can be explained by the relatively high level of working vacuum in which goats or sheep are milked (44 kPa). In Lacaune sheep Marnet et al. (1999) found thinner teats after milking (from –0.16 to 0.79 mm) in a working vacuum of 37 kPa. Similar results were reported by Peris et al. (2003a,b) in the Manchega sheep breed (–0.38 mm) in a working vacuum of 36 kPa. In cows Hamann and Mein (1990) found an increase in TEWT after milking that was 2% at 30 kPa, 8% at 50 kPa and 21% at 70 kPa. Later, Hamann et al. (1993) also found that the teats of cows were significantly thicker in higher vacuum levels. On the contrary, Le Du and Taverna (1989) found in cows that the TEWT after milking was lower than that observed before milking. They suggested that these findings depended on the characteristics of used materials and proved that the modifications in TEWT depended on the diameter of the liner as well as on its stiffness. Gleeson et al. (2004) also stated that the liner design appeared to have a bigger effect on the teat tissue changes than pulsation characteristics or vacuum level. In cows Hamann and Mein (1996a) recommended that the teat thickness changes after milking should be lower than +5% in order to prevent excessive teat oedema and greater than –5% in order to limit an excessive compression load of the liner over the teat. The increase in the teat thickness of >5% in cows after milking was significantly associated with new infections (Zecconi et al., 1996). It yet remains to be studied in sheep and goats.

In our study the TEWT decreased significantly from 4.98 in the 2nd week to 4.1 mm in the 12th week of the experiment with a parallel decrease in milk yield. On the contrary, Le Du and Benmederbel (1984) found that the teat thickness in French Saanen goats remained unchanged during the milking period.

Parity and type of birth did not influence the VOTS. On the contrary, TEWT increased significantly with increasing parities. This means that older goats have thicker teat ends. The type of birth did not influence the TEWT significantly, but a tendency of an increase in this variable was observed in dams that gave birth to and suckled two kids.

Phenotypic correlations showed that there was an increase in the machine stripped milk by increasing the VOTS. It should be said that the above milk fraction must be minimized in the case of machine milking. Goats with the lowest VOTS must be selected for this aim. No relationships were observed between VOTS and milking rate or milking time. On the contrary, in Lacaune ewes Marnet et al. (1999) found a significant positive correlation between VOTS and lag time, maximum and minimum milk flow rate and milking time. In cows Le Du and Taverna (1989) observed a positive correlation between VOTS and milking time and a negative correlation with the mean flow rate. A positive and significant correlation was found in our study between VOTS and TEWT before and after milking, which means that thicker teats required a higher vacuum level to overcome the resistance of the teat sphincter, probably because the thickest teats are also the more contracted ones.

CONCLUSIONS

The results of the present paper show that a low vacuum level (23.5 kPa) is required for the opening of the teat sphincter in goats of the indigenous Greek breed. This fact suggests that there is a need for a possible revision of the applied vacuum level. The thicker teat end wall and more resistant sphincter could be less favourable in the machine milking of these animals because of the strong relationships that exist between the vacuum for opening the teat sphincter, the teat end wall thickness and the level of stripped milk.

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