Management systems with extended milking intervals in ruminants: regulation of production and quality of milk.

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Management systems with extended milking intervals in ruminants: Regulation of production and quality of milk[1,2]

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ABSTRACT: This paper aims to compare different adaptive responses of the mammary gland of cows, ewes, and goats submitted to extended milking intervals in different systems of management. Depending on the species, these extended milking intervals can be characterized by the following milk removal approaches; 3 milkings every 2 d, elimination of 1 milking per week (i.e., 13 vs. 14 milkings per week), and once-daily milking with additional suckling (i.e., dual purpose system of suckling and milking) or without suckling (exclusive once-daily milking). All the high-yielding animals and breeds adapted without problems to being submitted to intervals between milking less than 20 to 21 h. Under these conditions, all ruminant species demonstrated only low and transitory variations in milk production and quality. Thus, management systems using such an interval are good tools for the dairy producer who wants to save time without important adverse economic impact. When animals have good mammary gland health, these management systems can be applied without preliminary adaptation. However, goats and some breeds of dairy ewes seem to adapt to once-daily milking better than cows. Additionally, goats and ewes with higher production levels demonstrate a lower reduction in milk yield. With goats, there is only a limited variation in milk quality and cheese-making capacity of the milk produced, but ewes and cows show a significant enrichment of milk constituents, especially in fat. This indicates some differences in the regulation of lactose, protein, and fat synthesis depending on the duration of the milking interval and provides interesting models for physiological studies on milk secretion and synthesis regulation. Anatomical and physiological characteristics of lactating cows and ewes, in terms of cisternal vs. alveolar volumes within the mammary glands, could contribute to different abilities in adaptation to different milking systems. In goats, however, other mechanisms, such as compliancy of the mammary gland and regulation of tight junction impermeability, could be involved in milk secretion regulation and, thus, could become new targets for genetic selection of animals better adapted to accept extended milking intervals.

Key words: cow, ewe, goat, mammary gland, milking interval, milk quality

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INTRODUCTION

In Europe, we have been taking part in a great diversification in the management systems of dairy animals during the last 10 yr. The model of management that takes priority today is a rational intensive model called "low cost, high return." This model is primarily based on the reduction of feed costs by better use of forage and pasture, when possible, and simplification of milking systems to reduce the workload of farmers and improve their living standards. It is now a very important option for farmers who would like to improve their quality of life without using external help because of the very high labor costs. Nevertheless, dairy farmers, the dairy industry, and consumers do not agree on the real impact of these milking management systems on animal physiology, animal welfare, and on milk quality. The scientific literature also provides conflicting information when these different systems of milking management are studied independently and on different periods and length of lactation. Thus, this review discusses and com-

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pares, in cows, ewes, and goats, 4 approaches based on a decrease in the frequency of milking: 1) the dual-purpose system of suckling and milking where milking is carried out only once per day (i.e., 24 h between milking) but compensated by an additional period of free suckling; 2) 3 milkings in 2 d (i.e., 16 h between milkings); 3) the elimination of 1 milking per week (i.e., 13 vs. 14 milking per week) to save time mainly during the weekend (i.e., 21 h between milkings); and 4) once-daily milking as simplified management system (i.e., 24 h between milkings).

Milking frequency is the main factor regulating milk yield and quality if feeding, welfare, health, and environmental conditions are adequate. The effect of extended milking intervals also varies depending on the species, breed, and genetic merit of animals used. This review compares ruminant species in their responses of milk production and quality when subjected to 1 of the 4 milking systems described previously and with respect to the anatomical and physiological characteristics of their mammary glands. The criteria involved in the ability of animals and species to adapt to these extended milking intervals are discussed.

DUAL-PURPOSE SYSTEM OF SUCKLING AND MILKING

At present, the dual-purpose system of suckling and milking is not used in dairy cows and goats. Although there is a growing interest by dairy producers engaged in biological systems to show an image of a more traditional and respectful approach to the animal's behavior and breeding on the farm. It is also the case for cheesemakers on their own farms because of their heavy workload. However, this type of management is standard practice for breeders of dairy ewes, particularly during the beginning of lactation (Caja, 1990). The suckling and milking system is an alternative to reduce the management of colostrum and bottle-feeding of lambs. In our experiments, the working time was reduced by 27%, which is particularly advantageous for on-the-farm cheese-makers (McKusick et al., 2002b). At the same, this system improves the milk yield of high-yielding ewes because normally the offspring cannot completely empty the dam's udder.

From a physiological point of view, work has demonstrated that the mother-offspring bond and maternal behavior strongly inhibited oxytocin release at milking but did not affect prolactin and cortisol release in ewes (Marnet and Négrao, 2000) and goats (Hernandez et al., 2002) or growth hormone release in cows (A. M. De Passillé et al., 2008). In fact, despite the incomplete milk ejection that limits milk removal during machine milking, and due to more frequent release of other galactopoietic hormones at suckling and to fall in the intramammary pressure after milking, milk secretion is never decreased and is even increased significantly compared with a system with only 2 exclusive milkings and stimulations per day.

Is the Milk of Equivalent Quality in Such a System?

A trial was carried out by our group on 18 East Friesian breed dairy ewes during the first 6 wk of lactation (McKusick et al., 2002b). In that study, the control group was milked twice daily (at 0630 and 1630) after removing lambs immediately at birth. The other group was subjected to a mixed management system with a milking at 0630, 1 free suckling period during the following 10 h and, finally, dam-offspring separation at 1630 during the following 14 h before milking the next day. This work demonstrated that mixed management drastically reduced the ejection of milk and reduced the quantity of milk collected by 40 to 60% at milking relative to the control ewes milked twice daily. The total quantity of protein collected was reduced by 53%, thus indicating that the protein concentration was maintained in the milk. However, the quantity of fat recovered was only 31% of that in the control group. The latter result could be explained by the retention of the alveolar milk, which concentrates the fat globules, rather than by a global reduction of milk fat synthesis because oxytocin injection allowed for removal of all the fat retained in the alveoli. No significant effect was observed on somatic cell concentration (**SCC**) in milk, which also indicates an absence of inflammation of the udder and, thus, no deleterious impact on udder health. Compared with controls, the total milk yield from suckled and milked ewes was increased by 42%, demonstrating the galactopoietic effect of the additional suckling period as described previously for cows (Bar-Peled et al., 1995). Other studies confirmed the galactopoietic effect of additional suckling in goats in such a dual-purpose system (Hadjipanayiotou and Louca, 1976; Papachristoforou et al., 1982; Peris et al., 1997). On the other hand, those studies did not find a significant decrease in the volume of milk obtained at milking (Papachristoforou et al., 1982; Peris et al., 1997) and even sometimes described an increase in milk obtained by machine milking (Hadjipanayiotou and Louca, 1976), despite the clear inhibition of milk ejection reflex in goats (Hernandez et al., 2002).

The addition of suckling between the 24-h milking intervals seems to be a good solution to avoid the negative impact the milk accumulating in the gland on milk yield. This practice is reasonable, easy to implement, and well accepted by the animal, as well by defenders of their welfare, because this milking regimen more closely mimics the natural maternal behavioral routines of the animals. Use of this practice in breeds with a high incidence of caprine arthritis encephalopathy virus or maedi visna virus must be strongly discouraged because suckling and close contact between mother and young are the main methods of cross-infection and viral dissemination.

THREE MILKINGS EVERY TWO DAYS

The practice of 3 milkings every 2 d is not generally used for all ruminant species because it creates an un-

usual work pattern, including 3 different schedules of milking and frequently a milking at night. However, it is the only milking system with a strict milking interval of 16 h that is reported in the literature within the physiological limits acceptable by the mammary gland (for review, see Davis et al., 1999). Greater intervals between milkings will reduce synthesis and secretion of milk and, thus, reduce milk yield. Nevertheless, a reevaluation in cows shows that this rhythm does not necessarily imply 3 strict intervals of 16 h between milkings, but may include varying intervals of 14, 18, and 16 h, for example (Rémond and Boit, 1997). By employing these 3 different intervals between milkings with an equivalent impact on milk production, milking outside of normal working hours can be avoided and could open a new future for this milking management system. There are no reports regarding use of a strict 16-h interval between milkings regimen in dairy goats.

We studied the application of this milking regimen in 2 groups of 24 East Friesian dairy ewes subjected, on d 90 to 160 of lactation, to either an experimental regimen of 16 h between milking or 12 h for the control group (McKusick et al., 2002a). The level of feed was not changed between the groups with the exception of 100 g of concentrate that was not provided at the entrance of the milking parlor at least once every 2 d in the experimental group, as it was for the control ewes. Results showed that there are no significant effects of this decreased frequency of milking on the production of milk, concentration of fat or protein, and SCC in milk. The duration of lactation also was not affected, and yet the total time invested in milking during a lactation is significantly reduced (27%).

Use of a 16-h interval between milkings was thus confirmed as not being deleterious to health of the mammary gland of ewes. Therefore, it seems to be a viable and simple approach with no negative impact on the milk quality, milk quantity, or net income, but with a positive impact on quality of life for the dairy producer due to substantial reduction in time needed to milk dairy cows and ewes. The only difficulty will be the adaptation of the farmers to this unfamiliar routine.

OMISSION OF ONE MILKING PER WEEK: A RE-EVALUATION

The practice of omitting 1 milking per week, generally applied during weekends, was developed and studied in France during the 1960s (Labussière and Coindet, 1968). Interest in this method was revived in France in 1996 so that dairy producers could manage a family farm without additional labor. Only about 8% of dairy producers in the Brittany region of France applied this system (Meffe et al., 2003). However, a number of dairy producers were interested in the system but were concerned about the negative impact it might have on their high-yielding animals in terms of amount and quality of milk produced, particularly because the only references available were old trials that were carried out on low-yielding cows (<4,000 kg/yr). The dairy processors, also fearing large variations in the manufacturing quality of the milk during the week, did not wish to promote this system before there was a clear reevaluation of its effects.

A trial carried out by our laboratory over 2 successive years in 2001 and 2002 tested the elimination of 1 milking per week on a herd of 83 Holstein cows of high genetic merit (>9,000 kg/yr) in the Derval experimental farm. During the first year, all cows in the herd were subjected to a milking regimen in which 1 milking per week was omitted. During the second year, a small group of 15 cows was milked twice daily in order to evaluate milk yield without disturbing the majority of the herd that remained in the milking system of omitting 1 milking per week. Analysis of multiple components of milk was carried out to evaluate the impact of this milking system on the manufacture of dairy products. For this experiment, it is important to note that the interval between milkings on the day that 1 milking was omitted was actually 21 h instead of 24 h, as generally implemented by the dairy producers on their farms (i.e., omission of the milking on Sunday evening with the milking on Sunday morning delayed 3 h). The diet was not modified compared with cows in the traditional system of 2 milkings per day, but particular attention was given to the hygiene of teats and cleanliness of the straw bedding.

During the first year, the cows adapted to this milking system very quickly and reduced the frequency of vocalizations (i.e., between 2 wk to 1 mo) at the time of the omitted milking. Milk loss, estimated by taking Friday and Saturday as a reference of return to the normal production, was only 3.5% in cows producing 9,083 kg of milk, with an average fat concentration of 4.08% and protein concentration of 3.06%. A large increase in fat concentration was observed on Monday evening (+0.6%), whereas the protein concentration did not change. The SCC significantly increased from Monday evening to Tuesday with a rapid return to the initial value on Wednesday evening. Some milk loss was observed in the straw bedding on Monday morning after omission of milking for a majority of the cows during the first third of lactation, requiring a higher workload for cleaning.

In the second year, comparison of the 2 experimental groups revealed no significant difference in milk yield or concentrations of fat, protein, lactose, or SCC in milk, although the variation in components during the week was similar to the first year of the experiment. By taking Friday and Saturday as a reference of return to normal production, we determined that during the period from Sunday to Thursday, milk yield decreased 2.5%, lactose content decreased 2.8%, protein content decreased 2.9%, and fat content decreased 0.85% (not significant), whereas SCC increased 17%.

Thus, it seems that a 21-h interval in dairy cows only modestly and temporarily affected the synthesis of proteins and milk, without significant reduction of

the total milk fat yield. On the other hand, this system was accompanied by a transient increase in the SCC of milk, which, in our conditions of good udder health of the experimental herd (<100,000 cells/mL), was not accompanied by a higher incidence of clinical mastitis. The pH; freezing point; concentrations of calcium, chloride, and phosphorus; lipolysis; profiles of fatty acids;, or various other milk components (i.e., various caseins, urea, lactoperoxidase, immunoglobulin G, bovine serum albumin, β-lactoglobulin, and α-lactalbumin) were not modified by this milking system.

A shorter trial, carried out in Spain (Ayadi et al., 2003) on Holstein cows at the end of their lactation and with an interval of 20 h between milking on Sunday evening and Monday morning, indicated a 3.7% decrease milk yield and a 2% decrease in lactose concentration, but no significant differences in protein, fat, or somatic cells concentrations over the entire week, comparable with results in our study. However, as in our experiment, large increases in fat concentration (+5%) and SCC (+100%) were also observed in milk collected on Monday. These results, combined with our results and noting the particularly weak effect on mammary inflammation, allow us to conclude that high-yielding dairy cows are adaptable to intervals of 20 to 21 h between milkings, although this may need to be avoided for cows having leaky teat sphincters and high SCC of milk. It appears to be an easy method to adopt without any extra workload (except for hygiene) and with a very limited negative economic impact compared with the gains in freedom and quality of life obtained.

From a physiological point of view, there was clear adaptation of the secretory cells over the 2 or 3 d following omission of the 1 milking. This model allows us to show that the regulation of milk secretion begins with the regulation of synthesis of caseins and lactose, of which osmotic effects limit the milk volume first before affecting the synthesis of the fat content in cows. However, the composition of milk was never affected, which makes it possible to reassure the dairy processors of the cheese-making quality of milk produced this way. The cows returned to a quantitatively and qualitatively normal level of production at the end of each week. Thus, it seems that 20 to 21 h between milkings is an interval that affects the synthetic capacity of the udder only temporarily. However, the temporary increase in SCC shows that this milking management system is possibly deleterious to udder health (i.e., disruption of integrity of secretory epithelium). The increase in SCC of milk could signify that the inflammatory response is one reflex of immune system activation that could be one of the regulatory mechanisms for milk production, as is the case when the animals cease lactation at dry off. Cisternal size, measured by ultrasonography, seems to be inversely proportional to the decrease in milk yield recorded with this milking system and may indicate that the main limitation of cows will be the storage capacity of their mammary glands (Ayadi et al., 2003).

Table 1. Decrease in milk yield during once-daily milking applied long term during lactation in cows

Decrease in milk yield, %	Breed	Reference
29	Prim'Holstein	Pomies and Rémond, 2002
31	Prim'Holstein	Cooper, 2000
35	Friesian/Jersey	Holmes et al., 1992
40	Swedish	Claesson, 1959
44	—	Woodward, 1931
44	—	Hesseltine et al., 1953
50	Swedish	Claesson, 1959

In small ruminants, this management system has only been tested in older experiments in Sarda ewes (Casu and Labussière, 1972), ewes of the Prealpine breed reared for meat production (Labussière et al., 1974a), and Alpine goats (Le Mens, 1978; Mocquot et al., 1978). Generally, the changes in milk yield and composition were comparable with results for cows. However, the response of goats and Sardinian dairy ewes (i.e., milk breeds) seems to be close to the response of cows (1 to 13% decrease in milk yield), whereas Prealpine ewes bred for meat seem to be much more sensitive to this management system (i.e., 26% decrease in milk yield). These results were the first to indicate the possible effect of cisternal storage to explain this different ability between breeds because Sardinian ewes and Alpine goats had a greater cisternal volume than Préalpine ewes (Labussière et al., 1974a; Labussière 1988).

ONCE-DAILY MILKING

The practice of once-daily milking has been the subject of older experiments worldwide and resulted in 30 to 50% decrease in milk yield until the last experiments conducted in the 1990s (Table 1). In Europe, once-daily milking has been viewed with interest after numerous publications from New Zealand, English, and French teams, and by application of this practice in Ireland. These experiments, conducted mainly during shorter periods of lactation, also reported results indicating approximately 38% decrease in milk yield (Stelwagen and Knight, 1997), but also provided more encouraging results indicating decreases in milk yield of only 7 to 26% (Stelwagen et al., 1994; Stelwagen and Lacy Hulbert, 1996; Rémond et al., 2002). The last trials published by French teams and encompassing the entire lactation, however, limited the use of this practice on farms because of the decrease of approximately 30% in milk production among high-yielding cows (Pomies and Rémond, 2005). This effect limits use of once-daily milking in high-yielding dairy cows for short periods or even for the second half of lactation when a lower negative effect is evident. This system may be of interest to adopt because of the dairy quotas in Europe, which continue to be enforced, or to release time for farmhouse tourism or for other off-farm activities.

Table 2. Decrease in milk yield during once-daily milking applied for the entire lactation in ewes

Decrease in milk yield, %	Breed	Reference
5	Sarda	Casu and Labussière, 1972
6	Sarda	Casu and Boyazoglu, 1974
10	Sarda	Flamant, 1974
10	Friesian × Sarda × Lacaune	Partearroyo and Flamant, 1978
10 to 19	Lacaune	Partearroyo and Flamant, 1978
12 to 15	Sarda	Casu and Boyazoglu, 1974
13 to 28	Chios	Papachristoforou et al., 1982
18	East breed	Bagdasarov, 1960
18	Awassi	Nudda et al., 2002
20	Israelian	Morag, 1968
23	Mérino	Nudda et al., 2002
24	Sarde	Nudda et al., 2002
25	Sarda	Partearroyo and Flamant, 1978
41	Sarda	Labussière et al., 1983
35 to 51	Prealpes de Sud	Labussière et al., 1974b

In ewes, once-daily milking is not used and has been tested only in older studies despite a renewal of interest. Decreases in milk yield varied between 5 and 41% depending on the studies and breeds of ewes (Table 2), with a lower decrease in milk yield in ewes with greater cisternal storage capacity. Primiparous ewes seem to be more sensitive to once daily milking, perhaps because of a less developed mammary gland (Casu and Boyazoglou, 1974). For all the ewes, Casu and Boyazoglou (1974) showed that the negative effect of once-daily milking on milk yield also could be reduced when applied after 2 wk of twice-daily milking, confirming that greater development of the mammary gland is required to optimize once-daily milking management.

In goats, this system is much more traditional in Europe [Canaries breed (Capote et al., 1999); Murciano-Granadina breed (Salama et al., 2003)] and in Asia Minor [Damascus breed, Papachristoforou et al., 1982)]. The use of this system in goats is of greater interest in France than for dairy cows because one-half of all French goat breeders are also cheese-makers, which compels them to undertake 3 activities as livestock breeders/owners, cheese-makers, and salesmen. However, as for ewes, there are only a few recent studies evaluating the response of goats to once-daily milking. Previous studies conducted over the entire lactation or evaluation over shorter periods for physiological investigations revealed decreases in milk yield of 6 to 40%, depending on the breed of goats (Table 3). Studies with low- to average-milk-producing goats noted an increase in milk protein and fat concentrations, as for studies with other ewes and goats. Nevertheless, dairy goat producers have the same fears as dairy cow farmers concerning the impact of such a once-daily milking system on their high-yielding goats producing frequently over 1,000 L per lactation.

In a recent study, we compared once-daily milking with the traditional system of twice-daily milking over the first 6 mo of lactation in Alpine goats that produce 850 L of milk each lactation. During the first month of lactation, twice-daily milking for the 2 groups was used to equilibrate the groups of animals. This study was carried out using a cross-over experimental design, making it possible to take into account the effect of the stage of lactation. Two succeeding years were devoted for verification of this effect and also to study its long-term impact on the goats. Similar trials also were carried out in parallel on another experimental farm in France (Le Pradel) with goats of higher genetic merit (>1,000 L of milk per lactation).

Results of the study revealed that the goats are not adversely affected by this system, with no specific vocalization or increase in agitation at the time when milking was suppressed (Marnet et al., 2005). No leakage of milk on the ground was observed and no clinical mastitis was detected over the 3 yr. On a more quantitative level, goats had a 15% decrease in milk yield relative to control goats milked twice daily during the experiment. This loss was similar regardless of whether once-daily milking was applied to the beginning (from 28 to 91 d of lactation) or middle of lactation (from 91 to 154 d of lactation). There was considerable variability among animals with some goats having milk production reduced nearly 30%, similar to Holstein cows milked once daily, whereas in other goats milk yield was decreased no more than 2% under the same treatment. Surprisingly, fat concentration was not affected (3.25% for once-daily milking vs. 3.17% for the control group with even a slight decrease in fat concentration at the beginning of trial for once daily milking group), whereas protein concentration increased significantly (3.04% for once-daily milking vs. 2.77% for the control goats), but enrichment was observed especially in the second half of the experiment. Relative to controls, the milk fat lipolysis was significantly less (1.1 to 0.5 mEq/100 g of fat) in goats under once-daily milking management.

The integrity of the secretory epithelium of the mammary gland was maintained with an overall unmodified

Table 3. Decrease in milk yield during once-daily milking applied in goats

Decrease in milk yield, %	Breed	Reference
6 to 7	Damascus	Papachristoforou et al., 1982
6 to 8	Canarian	Capote et al., 1999
15	Alpine	Marnet et al., 2005
18	Murciano Granadina	Salama et al., 2003
26	British Saanen	Wilde and Knight, 1990
26	Saanen	Boutinaud et al., 2003
21 to 40	Alpine	Mocquot, 1980
36	Alpine	Mocquot et al., 1978

Na^+ to K^+ ratio in milk of goats milked once or twice daily (Marnet et al., 2005). Only a slight, but significant, increase in the concentration of BSA in milk was detected within the once-daily milking group (186 to 221 μg/mL) temporarily over the first 8 d after the change of milking regimen from twice-daily to once-daily milking indicating leakage blood protein into the alveolar lumen. However, this leakage did not have any effect on the casein to whey protein ratio in the milk, and the coagulation yield even increased slightly (14.6 to 16% in the once-daily milking group). The SCC did not increase significantly (235,000 cells/mL for once-daily milking vs. 135,000 cells/mL for the control group), thus indicating only a weak inflammation of the mammary gland. It is important to note here the particularly low SCC of animals in our experimental herd that does not allow extrapolation to what would occur in a commercial herd, which generally have much higher SCC levels of up to 800,000 cells/mL.

During our last experiments carried out on a more practical level during 2 subsequent years, we were able to confirm all of these results and especially the lack of increase of fat concentration in milk from the once-daily milked goats (our unpublished results). An increase in the percentage of goats showing an inversion of concentration (i.e., when fat concentrations become lower than protein concentrations) in the middle of lactation was observed. Such a reduction of fat concentration for these goats that were only milked once daily could be due to lack of adaptation to level of feeding (e.g., too high concentrate quantity or acidosis). Second, milk ejection could have been affected slightly by the possible stress of the animals, resulting in retention of fat in the alveolar lumen. Third, high-yielding goats could have a different regulation or mammary strategy for use of the blood precursors used for synthesis of milk fat that could explain the lack of increase or the decrease in fat concentration observed. Fourth, it could be also due to a greater sensitivity to or a greater production of the precursor, *trans*10 C18:1, which is known to be an inhibitor of milk fat synthesis in the mammary glands of cows with low fat milk syndrome during the peripartum period (Baumgard et al., 2000). These last 2 possibilities are now under investigation in our laboratory. In addition, udders were not misshaped with the repetition of once-daily over several lactations. The persistence of lactation (i.e., maintenance in milk yield) seems to be greater during once-daily milking management (Marnet et al., 2005). This is also very interesting when considering high-yielding goats that often have lengthened lactation when there are problems with fertility after artificial insemination of these animals.

In experiments conducted at the Le Pradel experimental farm in France, where goats produce approximately 1,100 L/lactation, the decrease in milk production in goats milked once daily was also 15%, with fat concentration unchanged and a gain of 0.27% in protein concentration. Cheese yields per liter of milk were not affected. The application of once daily milking at this farm immediately after parturition seems more difficult to support in primiparous goats because they exhibit a greater decrease (>24%) in milk production relative to controls primiparous goats milked twice daily. This indicates that in goats, similar to ewes, an optimal mammary development is required to minimize the negative impact of this once-daily milking on milk yield. However, no deleterious effect was recorded during the subsequent lactation of these primiparous goats when they were milked twice-daily. Thus, once-daily milking is sustained better in goats than in cows and seems to be an advantageous alternative for simplification of the workload. Some dairy breeders who do not have a problem with workload imagine that because of the good adaptation of this management system to goats, once-daily milking can even be a way of increasing farm milk production and the income in the absence of milk quota policies (by the European Union or local dairy plants) or limits on nitrogen release into the environment. This could be achieved by doubling the herd and milking one-half in the morning and the other half in the evening.

From a physiological point of view, the 24-h-interval between milkings in goats induces the activation of regulatory mechanisms of the synthesis and (or) secretion of milk. This mechanism appears slightly different from that in cows and ewes, particularly for the regulation of milk fat synthesis that was reduced more than milk yield in some high-yielding goats.

WHICH CRITERIA FOR SELECTION OF ANIMALS BETTER ADAPTED TO EXTENDED INTERVALS BETWEEN MILKINGS?

A study performed on ewes (McKusick et al., 2002a) in which we measured the distribution of milk between the alveolar and cisternal compartments of the udders by testing all the intervals between milking, showed that between 20 and 24 h of accumulation of milk, alveolar volume did not increase further, whereas cisternal volume continued to enlarge. This result may indicate that if the gland cisterns are more important, then the transfer of milk from the alveolar component to the cisterns could continue and, thus, provide the animal with a greater capacity to counteract the negative ef-

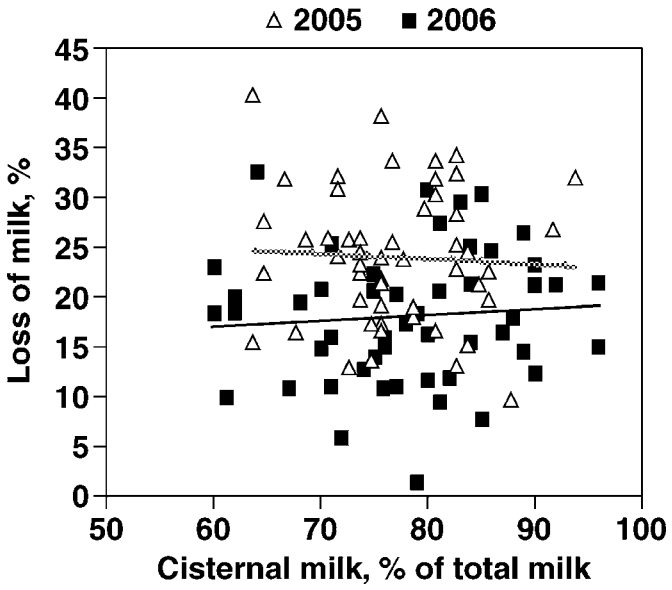

Figure 1. Relationship between cisternal milk volume (percentage of total milk) and decrease in milk production (loss of milk) after application of once-daily milking during 2 successive years (2005 and 2006) in Alpine goats. Source: P. G. Marnet; unpublished data.

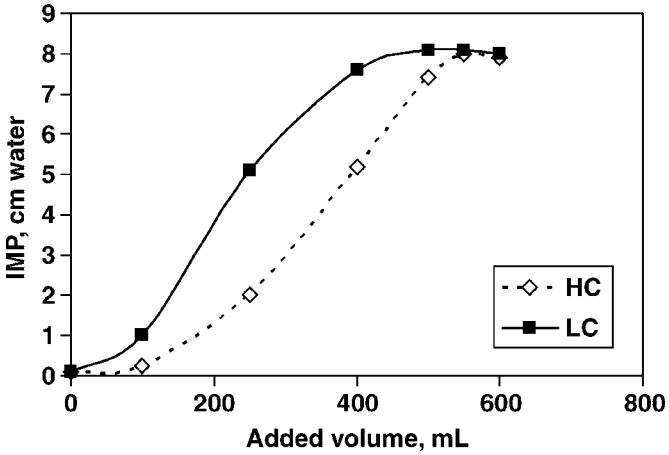

Figure 2. Example of udder-filling curves [intramammary pressure (IMP) vs. added volume] for 2 individual ewes with high compliant (HC) or low compliant (LC) udders. Increments of sterile physiologic saline were allowed to flow into each udder half. Intramammary pressure was measured after the addition of each increment. Source: P. G. Marnet; unpublished data.

fects of the accumulation of milk. This relationship between cisternal capacity and milk yield loss during once-daily milking was also confirmed by Knight and Dewhurst (1994), Stelwagen and Knight (1997), and Davis et al. (1998) who demonstrated that the cows with a greater ability to support once-daily milking were those having the largest cisterns. Because goats have a higher proportion of milk in their cistern than ewes or cows (70 to 90% of the total udder volume), they perhaps have a greater capacity to continue to produce milk during extended milking intervals due to this anatomical characteristic. On the other hand, the percentage of cisternal volume relative to total udder volume does not seem to explain this difference in ability to not suffer milk yield loss with longer milking frequencies among goats (Figure 1). This may indicate that another mechanism of regulation of milk synthesis is established in goats before the udder and their cisterns are completely full. Indeed, we showed that even after 24 h of accumulation of milk, the udder of goats is still able to enlarge its cisternal volume by transfer of alveolar milk after oxytocin injection. Another, rather close supposition would be based on a different ability of the udders to accept dilatation (i.e., compliance),

Table 4. Milk yield and intramammary pressure (IMP) by group of dairy ewes with different compliance of the udder[1]

		Half-udder milk fraction[2]			
Trait	Group[3]	CON	CIS	ALV	TOT
Machine milk yield, %	H	—	56.2 ± 3.0[a]	43.8 ± 3.0[b]	—
	L	—	62.3 ± 3.0[a]	37.7 ± 3.0[b]	—
Machine milk yield, L	H	0.44 ± 0.02[d]	0.30 ± 0.02[e]	0.24 ± 0.02[f]	0.50 ± 0.02[c]
	L	0.57 ± 0.02[b]	0.43 ± 0.02[d]	0.27 ± 0.02[ef]	0.65 ± 0.02[a]
IMP, cm H_2O	H	—	13.3 ± 0.6[c]	—	29.1 ± 0.6[a]
	L	—	12.3 ± 0.6[c]	—	24.1 ± 0.6[b]
P:V ratio,[4] cm of H_2O/L	H	—	45.6 ± 1.5[b]	—	58.6 ± 1.5[a]
	L	—	30.0 ± 1.5[d]	—	37.9 ± 1.5[c]

[a–f]Means for a trait with different subscripts differ, $P < 0.05$.
[1]Least squares means ± SE. Data from McKusick, 2001.
[2]Average values of both udder halves. CON = no injection, CIS = measured after administration of an oxytocin receptor antagonist, ALV = measured after cisternal milk had been removed from the udder and an injection of oxytocin had been administered, and TOT = the entire half-udder measured after administration of oxytocin.
[3]Ewes were ranked a posteriori on their udder halves pressure to volume ratio (P:V). H = ewes with a high P:V ratio (n = 15) and L = ewes with a low P:V ratio (n = 15).
[4]P:V ratio = IMP divided by machine milk yield.

thereby accounting for the effect of the intramammary pressure on mammary gland elasticity.

Measurement of intramammary pressure in the ewe mammary gland in response to an infusion of 100 to 200 mL of milk in each udder half showed that some udders have greater compliance. These are udders of ewes that produce more milk and have more cisternal milk (Table 4). In goats, udders with greater or less compliance also correspond to different shapes: globular udders when full and showing the shape of a sock when empty have high compliance, whereas udders with slightly different shapes when full or empty have low compliance (Figure 2).

What Mechanisms Could Be Induced by This Milk Accumulation?

The concept of an autocrine feedback regulator in the milk that inhibits milk secretion as milk accumulates in the udder is probably valid. However, the existence of only one specific peptide in the whey fraction of the milk, as described by the Hannah Research Institute group (Wilde et al., 1991, 1995), is questionable, based on our current results (A. Foisnet, S. Bouhalab, INRA-Agrocampus UMR STLO, Renees, France), and P. G. Marnet, unpublished results). No fraction corresponds to those described in the publications and patents of this group (Wilde et al., 1991, 1995). The mass spectrometric analysis of all proteins and peptides of the fraction in whey and in the range of molecular weights makes it impossible to find the published amino acid sequences of the FIL peptide. A biological activity on inhibition of milk synthesis exists; however, but is less efficient than the activity contained in the caseinic fraction. This confirms the assumptions made by Shamay et al. (2002, 2003), according to which release of caseino-phosphopeptides resulting from the enzymatic hydrolysis of caseins could be one way by which synthesis of milk could be regulated. Our studies confirm the role of these caseino-phosphopeptides, which, in addition to having a prominent effect during dry-off of the udder at the cessation of lactation, may inhibit milk synthesis temporarily and, thus, could be one of the inhibitory factors also regulating milk production during extended interval between milking. Because release of these phosphopeptides is dependent on hydrolysis of caseins by plasmatic enzymes, it is probable that the ability to support, without negative regulation, the extended intervals between milkings could be related to the capacity of the tight-junctions to remain tight for a long time.

CONCLUSIONS

To conserve time and for its ease and flexibility, once-daily milking could be the best system for dairy goat producers. However, this is not the case for cows and ewes breeders because of the greater impact of once daily milking on mammary gland physiology and udder health that limits the use of this system to only short periods, to the end of lactation, or both. Nevertheless, goat breeders could apply this management system throughout lactation in the near future due to the specific and surprising ability of this species to support milk accumulation with limited effect on production, udder health, or animal behavior. The specificity of fat metabolism and regulation of milk volume in goats needs to be investigated further to provide new knowledge about the method of regulation of milk synthesis in the mammary gland, which appears to be more complex than generally reported, and to improve the genetic selection of goats for greater ability to support extended milking intervals.

By comparison, occasional extensions of the milking interval to 20 to 21 h is well tolerated by all the high-yielding ruminants, if they begin with good mammary gland health. Thus, dairy producers, dairy processors, and consumers will not be concerned with the quantity and quality of milk obtained or with the welfare of the animals when one milking is eliminated each week. All the other milking management systems (dual purpose of suckling and milking, 3 milkings in 2 d) appear to be good tools for adapting practices to different economical, ethical, or social objectives.

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