Efficient Milking
Efficient Milking has been written to provide the base knowledge level and understanding of the complex subject of milk extraction to all DeLaval employees worldwide. It is from these physiological, biological and behavioural platforms that DeLaval products are developed. Our philosophy is to work in harmony with biology, the environment, and the natural processes of life toward optimum harvesting of nature’s most perfect food milk.

A wider use of this booklet in our dairy industry is encouraged. Copies will be made available in a variety of the world’s languages by DeLaval market companies. The many colourful and useful illustrations are available from DeLaval for formal training and instruction in dairy courses and institutes simply by contacting DeLaval wherever you are.

The author of Efficient Milking is Dr Kerstin Svennersten-Sjaunja, Dr Svennersten-Sjaunja’s PhD in Animal Science is a collaborative work of the Swedish University of Agricultural Sciences, DeLaval, and Karolinska Institute. Dr Svennersten-Sjaunja’s key research interest centers around lactation. No publication would be complete without providing recognition of those who collaborated with the author. While not practical to mention all contributors the following individuals are cited for their special efforts:

Dr Hans Wiktorsson, Dr Lennart Nelson, Mr Kjell Smidner, Mr Lennart Söderman, Dr Ole Lind, Mr Benny Örnerfors,

Finally, special recognition goes to Mr Gunnar Borgström whose illustrations bring the text to life in so many creative ways.

Don Calhoun
DeLaval Holding
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I. Introduction

Milk is one of the most important animal products for human consumption. The demand on dairy production is to produce high quality milk with a composition corresponding to the consumers demands.

During the last decades milk production in many parts of the world has gone through a revolution, a revolution which is still in progress. Milk is produced from fewer, but higher yielding cows. Structural changes have caused a decrease in number of dairy farms, while they have increased in size and use of high technology. This high technology has become an ordinary tool for the farmer.

The great improvements in dairy production are due to an interaction among the separate advances from the various disciplines. Genetic progress has resulted in increased lactation production from about 4000 kg 30 years ago to an average production today between 7000 and 12000 kg milk. Increased knowledge about the importance of proper management and feeding for optimal milk production has contributed as well.

Milking is a central part in dairy management to optimise production capacity and milk quality. Milking is not only a procedure where the milk is drained from the teats, it is an event where many physiological mechanisms are activated in the body of the lactating cow, events which influence mechanisms regulating production capacity, milk composition, feed intake and animal behaviour. The possibility to interact with the biology of the cow in order to produce milk with high quality and optimal yield is therefore partly through the milking technique and milking routines. Milking is also an occasion where the farmer often has the opportunity to control and observe the cow.

The aim of this booklet is to introduce the reader to the complex but also very fascinating subject of milk extraction. We will learn to understand how the lactating animal is functioning from a physiological point of view and see how the technique has succeeded to meet the biological demands from the cow.
What is special about a lactating animal?
Milk is for mammals the main nutritive source for the young while they have their greatest relative growth. Therefore the amount of milk and its composition produced by the lactating animal is very well adapted to the special needs of the young. The variation in milk composition between species is illustrated in Table 1.

<table>
<thead>
<tr>
<th>Species</th>
<th>Water %</th>
<th>Fat %</th>
<th>Casein %</th>
<th>Whey protein %</th>
<th>Lactose %</th>
<th>Ash %</th>
<th>Energy (kcal/100 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human</td>
<td>87.1</td>
<td>4.5</td>
<td>0.4</td>
<td>0.5</td>
<td>7.1</td>
<td>0.2</td>
<td>72</td>
</tr>
<tr>
<td>Rat</td>
<td>79.0</td>
<td>10.3</td>
<td>6.4</td>
<td>2.0</td>
<td>2.6</td>
<td>1.3</td>
<td>137</td>
</tr>
<tr>
<td>Dolphn</td>
<td>58.3</td>
<td>33.0</td>
<td>3.9</td>
<td>2.9</td>
<td>1.1</td>
<td>0.7</td>
<td>329</td>
</tr>
<tr>
<td>Dog</td>
<td>76.4</td>
<td>10.7</td>
<td>5.1</td>
<td>2.3</td>
<td>3.3</td>
<td>1.2</td>
<td>139</td>
</tr>
<tr>
<td>Horse</td>
<td>88.8</td>
<td>1.9</td>
<td>1.3</td>
<td>1.2</td>
<td>6.2</td>
<td>0.5</td>
<td>52</td>
</tr>
<tr>
<td>Cow</td>
<td>87.3</td>
<td>3.9</td>
<td>2.6</td>
<td>0.6</td>
<td>4.6</td>
<td>0.7</td>
<td>66</td>
</tr>
<tr>
<td>Reindeer</td>
<td>66.7</td>
<td>18.0</td>
<td>8.6</td>
<td>1.5</td>
<td>2.8</td>
<td>1.5</td>
<td>214</td>
</tr>
</tbody>
</table>

As an example, reindeer which are living in very cold areas, need to be provided with a thick adipose tissue under the skin whereby the milk consumed by the young has a high fat content in order to quickly develop the protecting adipose tissue. The pups of the rat are born naked and therefore need milk with a composition of the protein adapted to development of the fur coat.

The shape of the lactation curve differs among different species. Larger animals such as cows and goats have long lactation curves with peak production in the beginning of lactation, whereas smaller animals such as rabbits and rats have a short and conical curve, demonstrated in Figure 1.
In spite of the different species having different demands on composition and yield of milk, the production capacity is almost the same for all animals. Calculated from the correlation between the amount of milk produced per day and body weight it can be summarised that the milk producing capacity is around 1.7 ml milk/gram milk secreting tissue per day (Figure 2).

The modern lactating dairy cow has a much higher milk production than the calf needs. This is the result of the genetic breeding programs and the great improvements in feeding and management. Furthermore, the consumer demands on milk composition are not fully related to the biological capacity of the ruminants. Consumers and the dairy industry prefer a milk with a low fat content and high protein content. Therefore efforts are made to produce such a milk through breeding and by feeding. This alteration of milk yield and milk composition puts special demands on the modern lactating dairy cow.
Is it possible for the cow to meet these demands? Let us first discuss what happens during gestation and lactation from a biological point of view. During gestation and lactation the animal is exposed to a very exceptional physiological situation. During gestation the fetus has to be provided with nutrients in order to develop and grow to be born and during lactation the female animal has to produce a lot of milk to feed the young. To manage this, the female increases her food intake, changes the metabolism/food digestion and starts to build up body reserves (adipose tissue). The gastrointestinal tract is growing and its function is optimised. During lactation the animal continues to have a high calorie intake and often even increases its intake a lot more during this period. The body reserves built up during gestation are now used and the metabolism is shifted to a situation where the stored body reserves are broken down and used to provide energy for milk production.
How is this process regulated? During gestation a lot of hormones are activated which are regulating the metabolism and preparing the mammary gland for the coming lactation. After parturition the lactation continues to be regulated by different hormones originating from the brain, stomach and endocrine glands, but also from the mammary gland. Suckling is now the important stimulus for the mammary gland, directly or indirectly influencing hormones controlling lactation, food intake and behaviour. The finding that the mammary gland, is an organ that controls and not only an organ being controlled, is a very important statement when discussing milking technique. It has indeed lately been found that the teats are provided with nerves of different origin which during suckling/milking can influence different organs in the body and thereby different physiological events.

**Feeding the lactating animal**

The modern dairy cow has much higher demands for nutrients compared to her ancient sisters not selected for high milk production. Cows some hundred years ago produced milk enough for the calf, i.e. maximum 2-10 litres a day. It is not unusual that cows today are producing up to 60 kg milk per day, which is a tremendously high production in an evolutionary perspective. This high milk production is therefore associated with exceptionally high nutritional demands. For comparison, just prior to parturition the fetal calf requires approximately 10% of the cow’s net energy intake, while the energy requirement for milk synthesis can approach 80% of the net energy intake.

It is a well-known phenomenon in modern dairy production that the first part of lactation is associated with metabolic disturbances. During the first weeks of lactation the high-yielding cow is often in negative energy balance. The cow is producing high milk yields while she has difficulty to support herself with enough energy due to limited feed intake capacity (Figure 3).

To be able to produce very high quantities of milk she therefore is using her body reserves. In an evolutionary perspective it is not strange with a short period of negative energy balance, the animal’s metabolism is shifted from an anabolic (build up of energy reserves) to a catabolic situation (break down of body reserves). Since the dairy cow is producing much more milk than she was created for from the beginning, the way to succeed with feeding her during lactation is a real challenge.
However, it is not only during lactation that the feeding of the animal has to be given careful attention. It is well known that rapid rearing can result in an earlier age of first parturition, but rapidly reared heifers often have inferior milk yields. The initial ductular framework on which secretory tissue is subsequently laid takes place before puberty. If the heifers are rapidly reared, this growth is reduced and the mammary gland has more fat tissue compared to animals reared at a slower rate. Furthermore, these heifers have reduced plasma growth hormone, a hormone that highly influences lactation capacity. Therefore, the maximum recommended growth rate for Holstein heifers and heifers of similar type, is a growth around 600 grams per day in the period between 90 and 325 kg body weight and growth around 800 grams per day in the period from 325 kg up to three months before parturition (Figure 4).

Feeding during the dry period is also challenging. During this period feeding should be restricted to avoid fat cows which leads to metabolic disturbances during the beginning of lactation. It has been recommended that the pregnant cow at the end of the dry period should be adapted to high food intake in the beginning of lactation to avoid negative energy balance by a gradual increase of concentrate the weeks before calving. Research work is going on in this area and hopefully new light will be shed on the subject.
The dairy cow has, as a ruminant animal, special capacity to digest feeds with high amounts of fibres such as cellulose, feeds which generally are not very suitable for monogastric animals. Therefore, the feeding for dairy cows ought to consist of a ration with a high proportion roughage and low proportion concentrate. Today, to reduce the content of fat in the milk, farmers are feeding cows with high amounts of concentrate (including a high level of starch). A high level of starch and low level of fibres will alter the fermentation in the rumen. In the end this will influence fat metabolism in the mammary gland, resulting in lower milk fat content. Too high levels of concentrate might create metabolic disorders for the ruminants and lead to low milk fat syndrome.

What is then so special with a ruminant’s digestive tract? As mentioned above the unique ability of the ruminant is its possibility to digest fibres. This digestion is taking place in the rumen, and a lot of different bacteria and other microorganisms are responsible for this process. During the fermentation process carbohydrates are digested to volatile free fatty acids (VFA) such as acetate, propionate and butyrate, which are mostly absorbed through the mucosa of the rumen. The degradation of protein in the rumen results in 20-80% in microbial protein while the rest, 80-20 %, is undegraded and will be digested in the abomasum or intestine together with the microbial protein. The diet for dairy cows usually contains a relatively low amount of fat,
which is digested to glycerol and fatty acids. By products from the microbial metabolism are passed through to the other stomachs and absorption of different components takes place in different parts of the intestine. The rumen, reticulum and omasum can be compared to a kind of foregut fermentation chamber. It is important to have in mind that when we are feeding the cow we are first feeding the microbes, which in turn are feeding the dairy cow (Figure 5).

How much feed does a high producing cow consume? The amount of feed the dairy cow consumes is dependent on factors related to the cow as well as to the environment. Basically the appetite of the cow is regulated by hormonal control and rumen fermentation acids. Furthermore, it has been observed that fatness reduces feed intake. Lactation stage, milk yield, feed composition, and frequency of feeding are also factors of great importance. Generally, a dairy cow of 600 kg body weight producing around 50 kg milk consumes about 25 kg dry matter of feed per day, or in other words a high producing cow must at least consume 4% of her bodyweight on dry matter basis per day. The total water consumption is between 3.5 and 5.5 litre/kg dry matter intake.
III. The mammary gland

Anatomy of the mammary gland

The gross anatomy of the mammary gland differs a lot among different species. The number of glands and teats are not the same for the cow, the sow or the horse. However, the microscopic anatomy is very similar among species.

The development of the mammary gland starts early in the fetal life. Already in the second month of gestation teat formation starts and the development continues up to the sixth month of gestation. When the calf fetus is six months, the udder is almost fully developed with four separate glands and a median ligament, teat and gland cisterns.

The developments of milk ducts and the milk secreting tissue take place between puberty and parturition. The udder continues to increase in cell size and cell numbers throughout the first five lactations, and the milk producing capacity increases correspondingly. This is not always fully utilized, since the productive life time of many cows today is as short as 2.5 lactations.

The mammary gland of the dairy cow consists of four separate glands each with a teat. Milk which is synthesized in one gland cannot pass over to any of the other glands. The right and left side of the udder are also separated by a median ligament, while the front and the hind quarters are more diffusely separated.

The udder is a very big organ weighing, around 50 kg (including milk and blood). However, weights up to 100 kg have been reported. Therefore, the udder has to be very well attached to the skeleton and muscles. The median ligaments are composed of elastic fibrous tissue, while the lateral ligaments are composed of connective tissue with less elasticity. If the ligaments weaken the udder will become unsuitable for machine milking since the teats then will often point outward (Figure 6).

The mammary gland consists of secreting tissue and connective tissue. The amount of secreting tissue, or the number of secreting cells is the limiting factor for the milk producing capacity of the udder. It is a common belief that a big udder is related to a high milk production capacity. This is, however, not true in general, since a big udder might include a lot of connective and adipose tissue. The milk is synthesized in the secretory cells, which are arranged as a single layer on a basal membrane in a spherical structure called alveoli. The diameter of each alveoli is about 50-250 μm. Several alveolies together form a lobule. The structure of this area is very similar to the structure of the lung. The milk which is continuously synthesized in the alveolar area, is stored in the alveolies, milk ducts, udder and teat cistern between...
milkings. 60-80% of the milk is stored in the alveolies and small milk ducts, while the cistern only contains 20-40%. However, there are relatively big differences between dairy cows when it comes to the cistern capacity. This is of importance for the milking routines to be applied (see later) (Figure 7).

The teat consists of a teat cistern and a teat canal. Where the teat cistern and teat canal meet, 6-10 longitudinal folds form the so called Fürstenbergs rosette, which is involved in the local defense against mastitis. The teat canal is surrounded by bundles of smooth muscle fibres, longitudinal as well as circular. Between milkings the smooth muscles function to keep the teat canal closed. The teat canal is also provided with keratin or keratin like substances which between milkings act as a barrier for the pathogenic bacteria.

The mammary gland is densely innervated especially in the teat. The skin of the teat is provided with sensory nerves which are sensitive to the suckling performed by the calf, and thus influenced by pressure, heat and frequency of suckling. The udder is also provided with nerves connected to the smooth muscles in the circulatory system and the smooth muscles in the milk ducts. However, there is no innervation directly controlling the milk producing tissue.

The mammary gland is very well supported with blood vessels, arteries and veins. Right and left udder halves generally have their own arterial supply, there are some small arterial connections that pass from one half to the other. The primary function of the arterial system is to provide a continuous supply of nutrients to the milk synthesizing cells (Figure 8a).
Figure 7. Schematic picture of the anatomy of the udder.
To produce 1 litre of milk 500 ltr. of blood have to pass through the udder. When the cow is producing 60 litres of milk per day, 30,000 litres of blood are circulating through the mammary gland. Thus, the high producing dairy cow of today is exposed to very extreme demands.

The udder also contains a lymphatic system. It carries waste products away from the udder. The lymph nodes serve as a filter that destroy foreign substances but also provide a source of lymphocytes to fight infections. Sometimes, around parturition first calvers suffer from oedema, partly caused by the presence of milk in the udder which compresses the lymphatics (Figure 8b).
Milk secretion and milk composition

Milk synthesis takes place in the alveoli where the milk secreting cells in the mammary gland are provided with a continuous supply of nutrients (Figure 9).

Milk fat consists mainly of triglycerides, which are synthesized from glycerol and fatty acids. Long chained fatty acids are absorbed from the blood. Short chained fatty acids are synthesized in the mammary gland from the components acetate and beta hydroxybutyrate which have their origins in the blood. Milk protein is synthesized from amino acids also with origin from the blood, and consists mainly of caseins and to a smaller extent whey proteins. Lactose is synthesized from glucose and galactose within the milk secreting cell. Vitamins, minerals, salts and antibodies are transformed from the blood across the cell cytoplasm into the alveolar lumen (Figure 10).
The composition of the milk varies between different breeds but also during lactation within breed (Table 2).

<table>
<thead>
<tr>
<th>Breed</th>
<th>Total solids %</th>
<th>Fat %</th>
<th>Casein %</th>
<th>Whey protein %</th>
<th>Lactose %</th>
<th>Ash %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown Swiss</td>
<td>12.69</td>
<td>3.80</td>
<td>2.63</td>
<td>0.55</td>
<td>4.80</td>
<td>0.72</td>
</tr>
<tr>
<td>Holstein</td>
<td>11.91</td>
<td>3.56</td>
<td>2.49</td>
<td>0.53</td>
<td>4.61</td>
<td>0.73</td>
</tr>
<tr>
<td>Jersey</td>
<td>14.15</td>
<td>4.97</td>
<td>3.02</td>
<td>0.63</td>
<td>4.70</td>
<td>0.77</td>
</tr>
</tbody>
</table>

In the beginning and at the end of lactation the fat and protein contents are higher compared to mid lactation (Figure 11).

The higher concentration of dry matter in milk at early lactation is due to the special needs for the young. As an example, the higher contents of protein during the first days after parturition depends upon the high amounts of immunoglobulins. On average the milk from dairy cows has a fat content between 3.0 and 5.5%, protein content between 3.0 and 3.8% and lactose in the range of 4.0 and 4.8%.

Are the yield and composition possible to influence?

It is well known that the amount of milk to be produced is highly influenced by the amount of feed given to the animal. It is also partly possible to influence the composition of the milk by feeding, especially by the composition of the feed. As an example, diets with low fibre content or diets with a high ratio of starch rich concentrate can cause a decrease in milk fat content. Such diets may alter the volatile fatty acid composition in the rumen, which influences the fat metabolism in the mammary gland. It is, however, more difficult to alter the protein content through feed composition. The possibility to alter milk composition through milking is also evident, but is most related to fat content and less to protein content. The content of fat and protein in milk are also important factors in the breeding programs.
**Milk letdown**

Ancient people were already aware of the importance and need to stimulate the milk ejection reflex. On paintings in caves the effect of vaginal stimulation for milk ejection was described as well as the importance to have the calf close to the cow during milking. How important is the stimulation of the milk ejection reflex during milking in our modern dairy cows? Is it a phenomenon, the importance of which, has disappeared through genetic improvements? In order to answer those questions the biology behind milk letdown will be discussed.

During milking and suckling nerve receptors in the skin of the teat that are sensitive to pressure are activated. This mechanical stimulation causes impulse transmission to the pituitary gland in the brain whereby the hormone oxytocin is released. The hormone is transported to the udder via the blood. In figure 12 a schematic figure of milk ejection reflex is presented.

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**Figure 12.**
Milk ejection reflex. Stimulation of the teats (1), causes nerve impulse transmission via the spinal cord (2) to the pituitary gland (3), where oxytocin is released and thereafter is transported to the udder via the blood (4).
In the mammary gland the hormone causes the myoepithelial cells surrounding the alveoli to contract whereby the milk is pressed out to the milk ducts and milk cisterns (Figure 13).

The time it takes from beginning of teat stimulation to milk letdown is about 30-60 seconds, but varies from cow to cow and also within the cow depending on the stage of lactation. It has been postulated in former times that the oxytocin secretion is momentary and the release just happens once during milking. Recent research has, however, indicated that oxytocin is released during the whole milking procedure.

The milk ejection reflex, including oxytocin secretion, can be stimulated in many ways such as application of different tactile teat stimulation, by the presence, sight or hearing of the calf and by feeding concentrate in relation to milking (Figure 14). The most efficient stimulation of the teats for milk let down is performed by the calf. An optimal milking technique should therefore imitate the suckling. The suckling done by the calf includes pre-stimulation, milk intake and post stimulation.

Why teat stimulation
Prestimulation
Prestimulation is in general the procedure performed before application of the teat-cups, including cleaning and drying the teats, massaging the teats and udder and drawing control milk. During the pre-stimulation the receptors in the teats are stimulated and the milk ejec-
tion reflex is activated. This results in milk letdown where oxytocin already has started to act on the myoepithelial cells when the milking machine is attached to the udder. A shorter milking time, a higher milk flow and in some cases a more efficient milk removal is the benefit of a proper pre-stimulation. Since the milk ejection is already activated when the milking machine is attached to the udder, the milk flow curve very seldom is bimodal (Figure 15).

Figure 14.
Milk ejection can be stimulated in different ways, such as tactile stimulation of teats, sight or hearing of the calf, noise from the milking machine and in some cases by feeding concentrate.

Figure 15.
Effect of 1 min premilk- ing manual stimulation on average oxytocin profile (red line) and milk flow (blue line) during milking. Milking began immediately at time 0; arrows show start time of stripping. (Adapted from Mayer et al J. of Endocrinol, 103: 355, 1984).
This means that there is no delay in flow between milk coming from the cisterns and milk coming from alveolar area, which improves teat treatment. The prestimulation can be performed either manually or by the machine. However, so far we haven’t found a mechanical variant as efficient as the hand.

**Post stimulation**

Post stimulation can be looked upon as the procedure where manipulations of teats and udder take place after the milk flow generally has decreased or stopped. Machine or hand stripping are examples. In experiments performed on dairy cows, it has been found that machine stripping or “extra” post stimulation (the last minute of milking was shifted from machine milking to hand milking) resulted in four to five percent higher milk production. In other species it was found that continued suckling after milk intake stimulates a higher milk production. The effect on milk production due to post-stimulation might be explained by activation of local regulatory mechanisms within the udder. These mechanisms might influence the emptying of the udder and also the capacity of the milk secreting cells.

**Stimulation during milking**

How the tactile teat stimulation on the teat during milking is performed is of great importance. It has been demonstrated that milking related release of the hormones oxytocin and prolactin is influenced by the tactile stimulation of the teats. In experiments where hand milking was compared to machine milking (hand milking is the milking procedure which imitates the calf suckling very well) it was found that the milking related releases of these hormones were both higher and prolonged during hand milking compared to machine milking. This effect can partly influence the milk production capacity.

During teat stimulation also local regulatory mechanisms of nervous origin in the mammary gland can be activated. A very good example demonstrating the importance of local mechanism in the mammary gland is the lactating kangaroo. She can feed two young (joeys) of different ages from two adjacent mammary glands with milk adapted to the special demands for each young. The bigger young has his (her) own teat producing milk related to his (her) demands, while the smaller young has his (her) own teat producing milk related to his (her) special demands, despite that both glands are exposed to the same hormonal and nutritional environment. It is only through the different suckling application the composition as well as the amount of milk to be produced in the specific glands can be regulated to the different demands from the young.
It has also been indicated in dairy cows that activation of local mechanisms is of importance for both milk production capacity and milk composition. In experiments it was found that hand milking resulted in a higher milk production and milk with a higher fat content compared to machine milking (Figure 16). The physiological mechanism behind these results is not yet fully elucidated. There are indications of the existence of local nervous reflexes in the udder, influencing mechanisms whereby the capacity in the milk secreting cell can be increased. Indeed, already during the fifties and sixties Russian scientists were aware of this phenomenon.

Another very interesting finding in monogastric animals and ruminants is that suckling/milking also might activate hormones in the stomach. However, what does this mean and what is the importance of this? Imagine a cow producing 100 kg milk per day - a very high milk production capacity. Giving this high amount of nutrients and calories is not possible unless the animal is consuming large amounts of nutrients. During the suckling/milking procedure the hormones in the stomach are activated (Figure 17). Some of these hormones which are activated during milking influence the feed intake behaviour and some of the hormones exert a growth stimulating effect of the gastric mucosa. It is therefore possible that the milking related release
of these hormones is involved in the adaption of the gastrointestinal tract during pregnancy and lactation in order to facilitate the enhanced food intake which is of vital importance. Having in mind that milking might influence feed intake indirectly points to the importance of appropriate cow management around milking.

Consequently, the mammary gland is an organ that is controlled by hormones and supported by nutrients in order to produce milk. However, the mammary gland is an organ that also controls its own function as well as it controls other organs in the body. Some of these control systems are activated through the milking/suckling process, which points to the high importance of how the machine is stimulating or acting on the teat during milking.
Why efficient milk removal?

Efficient milk removal is one important point regarding milking technique and milking routines. There are many reasons for this. Efficient milk removal results in a higher milk yield. The composition of the milk is influenced, in particular the fat content. When the farmer is paid according to the fat content of the milk it is significant to empty the udder as completely as possible, since the last portion of the milk has the highest fat content (Figure 18). From our own studies fat contents as high as 15-20% have been observed in the strip milk.

An important finding that supports the idea behind an efficient milk removal is the observation that the milk contains a protein which acts with a negative feed back control on the milk secreting cells. The inhibitor is synthesized in relation to the milk. As it works directly on the milk secreting cell it is important to empty the alveoli as completely as possible. In experiments performed on lactating goats one udder half was emptied completely while the other one was unmilked. The emptied gland was immediately filled up with sucrose solution and in this gland the milk secretion continued despite the high udder pressure. Conversely, in the unmilked udder quarter the milk secretion was inhibited. This observation strengthened the hypothesis about inhibitor substances present in the milk, which suppress milk secretion.

Figure 18.
A typical curve showing the rise in fat percentage of consecutive fractions taken during a normal milking and at subsequent milkings after injections of oxytocin to remove residual milk. (Adapted from J. Johansson, Acta Agric Scandinavia. 2:82, 1952).
From udder health point of view an efficient milk removal is important. However, the ambition to empty the udder as completely as possible doesn’t mean that we can allow over milking of the teats, which indeed can cause bad teat treatment and result in mastitis.

**Milking intervals**

There is a big variation in milking intervals between milk producing countries. In most countries 8-16 hours milking interval is common practice due to the labour situation. On larger farms 12-12 hours milking interval is often practiced. Twelve hour’s interval is the most optimal milking interval with twice daily milking. Milk production (kg milk) increases a couple of percentage points with equal intervals compared to unequal milking intervals.

What is the mechanism behind this phenomenon? Milk secretion starts to decline 10 hours after the previous milking, while udder pressure is increasing. 35 hours after previous milking the milk secreting process has stopped (Figure 19).

From the discussion above, obviously udder pressure alone is not the only factor regulating milk secretion rate, but also the discussed inhibitor mechanisms. Consequently, to optimise milk production the length of milking intervals has to be taken into consideration.

**Figure 19.**
The rise in intramammary pressure and the fall in milk secretion rate with lengthening milking intervals. (Adapted from Hamann & Dodd, in Machine milking and lactation, ed Bramley et al, 1992).
Milking frequency

Milking twice a day has long been the common practice in industrial countries, mostly due to the labour situation for farmers. However, in some countries where labour was rather inexpensive, more frequent milking was practiced. During the last decade focus has been put on milking more frequently again, in particular in high yielding herds. The benefits of more frequent milking are many.

Changing from milking twice a day to three times a day increases milk production markedly. Published data show increases from 5-25% more milk per day. In addition lactation becomes more persistent and prolonged. The reason why milk production increases with a more frequent milking could be a more frequent exposure of hormones stimulating milk secretion to the mammary gland. However, as mentioned above the milk contains an inhibitor with negative feed back control on milk secretion. A more frequent removal of this inhibitor therefore results in a higher production. An interesting finding in this respect is that cows with a small udder cistern are more sensitive to the frequency of milking. The smaller the cistern the greater the effect of frequent milk removal on milk production and the bigger the cistern the less the response to frequent milking.

Frequent milking has both long term and short term effects. The short-term effect is an increased milk production due to enhanced activity in the milk secreting cells, while the long term effect is increased production due to increased number of milk secreting cells. The latter indicates that it is possible to influence the number of milk secreting cells during an established lactation, which is of importance to the milk producing capacity (Figure 20).

Figure 20. Short, medium and long term effects of 3 x daily milking on lactation. (Adapted from Hamann & Dodd, Machine milking and lactation, ed Bramley et al, 1992).
Udder health has been reported to be improved with more frequent milking. However, it is worth noticing that teats have more sores, chaps and lesions with more frequent milking. On the other hand, the rates of new infections have decreased and the level of somatic cells in the milk show a tendency to decrease. More frequent milking leads to a more frequent rinse out of bacteria from the gland, which partly can explain the observations with an improved udder health (Figure 21).

Feed consumption seems to be influenced by frequent milking. It has in some experiments been reported that increased milk production by 10-15% is followed by an increased feed consumption by only 3-5% (Table 3).

How is this possible? It has been observed that the more frequently milked animals are drawing on their body reserves to a greater extent than twice daily milked animals. It is also possible that their metabolism is more efficient due to a more frequent activation of endocrine

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**Table 3.**
Increase in dry matter intake (%) and milk production (%) when cows were milked three and four times a day compared to twice a day. (Adapted from Ipema & Benders, In Proc. Int. Symp. on Prospects for Automatic Milking, 1992).

<table>
<thead>
<tr>
<th>Milking frequency</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk yield</td>
<td>100%</td>
<td>114%</td>
<td>115%</td>
</tr>
<tr>
<td>Dry matter intake</td>
<td>100%</td>
<td>103%</td>
<td>104%</td>
</tr>
</tbody>
</table>
systems related to metabolism. Indeed, it has been indicated that gastrointestinal hormones are activated during milking and it has been demonstrated in monogastric animals that the milking related hormone oxytocin is involved in the maternal metabolism.

Maybe the most important benefit of more frequent milking is improved animal welfare. It has been observed that most high yielders will not lie down during the last few hours before milking. Moreover, many high yielders are producing up to 60 kg milk per day and are milked twice a day with 8-16 hour milking intervals. This means that those cows are yielding nearly 40 kg milk during morning milking. Cows with such high amounts of milk in the mammary gland must be exposed to a tremendously high udder pressure which undoubtedly will cause discomfort. Indeed it has been observed that high yielding cows want to be milked more frequently than twice or three times a day when they have their own choice.

In summary, increased milking frequency affects the high producing dairy cow in a positive way with respect to production, health and animal welfare according to current observations. A more frequent milking than twice daily is better adapted to cows normal behaviour and need, since the calf is suckling as frequently as 4-7 times per day.

**Milking routines**

It doesn’t matter how well the genetic potential and feeding of the high yielding dairy cow has been taken into consideration in order to achieve optimal milk production if milking routines and milking equipment are not optimal. The milking routine has to be performed in a consistent way. The tube alignment has to be correct and also the installation of the milking equipment is important.

An optimal milking routine includes different steps such as: cleaning teats and udder, manual prestimulation, fore milking, and teat dipping when needed after milking. A proper manual prestimulation of the teats facilitates milk ejection. The importance of pre-stimulation has been discussed previously.

How will an optimal pretreatment be performed? Experimentally the importance of a strict milking routine has been demonstrated from a production point of view. Lactation production was studied where cows were exposed to different milking routines. A strict routine (cleaning and drying teats and udder for around 30 seconds and application of milking machine within 60 seconds from start of stimulation) resulted in an increased lactation production of about 450 kg. The control treatment was a routine with a short drying time and variable waiting time (Figure 22).
The teats and udder have to be cleaned and dried for the sake of good milk quality. Contamination from manure bacteria, and bacteria spores should be minimised. The teats should be cleaned by a separate towel for each individual cow in order to prevent transmission of mastitis pathogens between cows. If possible each corner of the towel should be used for separate teats to prevent transmission of pathogens within the cow.

When creating a good milking routine it sometimes helps to start using routines which will create positive emotions for the cow. During the seventies scientists demonstrated that feeding during milking resulted in a more efficient udder emptying, higher peak flow and a tendency towards increased production. The observation resulted in a recommendation to feed concentrates in the parlour in some countries.

But what was the mechanism behind this observation and is it worthwhile to continue feeding concentrate in the parlour? Interestingly, it has been found that feeding during milking both prolonged and increased the milking related release of the hormone oxytocin (Figure 23). From a production point of view it was further indicated that milking and feeding simultaneously increased milk flow, decreased milking time and showed a tendency to increase milk production.

However, more research work is going on to evaluate when it is most optimal to feed cows around milking. Will it be just before, during or after?

Figure 22. Effect of pretreatment on milk production, second and third lactation cow. Cows were exposed to a standard milking routine consisting of 31+/-9s premilking stimulation and 1.22+/-0.25 min interval and a control routine consisting of 17+/-5s premilking stimulation and 3.06+/-1.56 min interval. (From M.D. Rasmussen, J. Dairy Sci. 73:3472, 1990).
The milk ejection reflex might be inhibited as well. There are different types of inhibition, centrally in the brain or locally within the udder. What then can cause inhibition of the reflex? Rough treatment of the cows by the milker, discomfort during milking caused by the milking machine, unfamiliar surroundings and inconsequent management are several examples.

In order to stimulate the milk ejection reflex and not to inhibit it, it is very important to treat the cows in the most proper way both during and before milking. Milking represents a very complex sequence of conditioning processes. The very first cues indicating approaching milking (noise of milking machine being turned on, release of cows from stanchions, etc) starts the complex series of psycho-physiological processes that prepare the cow for milk let down. If this process is disturbed in one way or another milk ejection can be inhibited. Therefore the recommendation will be consistent timing of routines, such as udder wash, teat cup application and synchronization of other routines such as feeding or preparing of bedding. The events should take place in a regular order every day.

\[\text{Figure 23. Daily plasma oxytocin values (pM), when cows were: milked and fed together on four consecutive days and milked and fed separately on four consecutive days. (Adapted from Svennersten et al Acta Physiol Scand, 153:309, 1995).}\]
Teat treatment/mastitis

The prerequisite to produce milk in an economical way is to have a relatively high yield with high quality, which means high production from healthy animals not suffering from any kind of disease in the mammary gland. Mastitis is the most common and costly disease in dairy herds. In many cases the farmer is only aware of the clinical cases (Figure 24).

Figure 24. Clinical cases (A) and subclinical cases (B) of mastitis. (Adapted from Nelson Philpot, Mastitis Management, 1978).
It has been reported that clinical mastitis rates are generally 20-100 cases/100 cows per year. Subclinical infection levels are 5-35% of quarters infected by a major pathogen bacteria. The clinical mastitis is rather easy to detect for the farmer. The symptoms are clotting and discolouration of the milk, and the gland becomes hard, red or swollen and in severe cases the cow has fever and loss of appetite. The subclinical mastitis can be harder to detect, since both the milk and udder can appear rather normal, while the somatic cells in the milk increase (Figure 25).

©

Figure 25. Diagnoses of mastitis: A-clinical, B-subclinical.

A. Clinical mastitis (with symptom)
- Udder: swelling, redness, soreness
- Milk: blood; flakes or clots, watery

B. Subclinical mastitis (often without symptom)
- Diagnosis by laboratory methods such as bacterial growth or cell count

What is mastitis? Mastitis is an inflammation in the mammary gland which can be caused by bacterial infections or trauma. When bacteria are growing, they release metabolites and toxins that stimulate the defense mechanisms in the cow. The inflammation response leads to a migration of white blood cells from the peripheral circulation into the udder. The cell count of the milk increases from normally 100 000
cells/ml or less per udder quarter up to several million per ml. The increased cell count is accompanied by an activation of several milk enzymes (Figure 26).

The pathological consequences of mastitis are tissue damage and alteration of secretory function. This leads to reduced milk yields and changes in milk composition. A correct estimation of the loss in milk yield is hard to do, since non-infected udder quarters tend to compensate for the decrease in yield of the infected quarter. The mechanism behind the regulation of this compensation is still unknown. Regarding the altered milk composition, fat and lactose levels are dropping, while total protein levels change only slightly serum proteins are
increasing and casein are decreasing leading to deteriorated cheese making quality. The milk concentrations of ions are increasing resulting in an increased milk conductivity (Figure 27).

How is the milking machine influencing mastitis? The milking machine can facilitate the transmission of pathogens between cows and between udder quarters. The action of the milking machine can also cause bacteria to move from the exterior of the teat into the teat sinus, caused by excessive vacuum fluctuations. Furthermore, vacuum fluctuations in the claw can cause milk moving between teat cups. The teat end can be affected by the machine resulting in teat lesions, which could be colonized by bacteria. Too high vacuum levels, overmilkling and inadequate pulsation (insufficient or too short massage phase) are factors that might contribute to damage of the teats. These examples demonstrate the importance of how the milking machine is manufactured but also how the farmer is using it.

Figure 27. The relationship between somatic cell count in milk, the quantities of the components in milk and milk production. (From Giesecke et al, In Practical mastitis control in dairy herd, 1994).
When manufacturing milking machines, it is very important to verify that a new milking machine is not influencing the teat negatively. A method for measuring teat treatment has been developed where the changes in thickness of the teat after milking is compared to the thickness before milking. If the milking is performed in a proper way, from a teat treatment point of view it seems likely that the teat thickness after milking is not altered compared to before milking (Figure 28). However, teat lesions or abnormalities on the teats, which are not related to machine milking are not unusual. It is therefore important to have in mind that several factors in the environment can influence the teat and udder health.

![Figure 28. Development of teat end thickness values (Cutimeter) before and immediately after milking in relation to different milking methods and trial periods. (Hamann and Stanitzke, Milchwissenschaft, 45:632-637, 1990).](image)

What can the farmer do to avoid mastitis? Generally it can be said that a good hygienic milking routine is the prerequisite. Premilking preparation where the teats are washed with individual towels containing disinfectant is recommended. Mastitic cows or cows with increased somatic cell counts should be milked at the end of milking and teat dipping should be practiced when needed. Keeping a high hygienic level on the environment is also very important factor which means keep the cows clean and keep a good hygiene of the bedding. Last but not least, the milking machine must be regularly checked, tested and serviced, such as vacuum levels, pulsation rate/ratio, and replacement of rubber parts.
Cow behaviour/ethology
A successful animal husbandry must respect the basic biological requirements of the animals. This means that we need to have knowledge about animal requirements for space, air supply, thermal protection, nutrition, behaviour etc. Regarding behaviour it is important to have an understanding of the cow’s ability to detect events in her surroundings, memorize the specific significance and act accordingly. As an example, efficient management requires good knowledge about learning abilities of dairy cows, in particular when it comes to milking parlours and robotic milking systems.

The different ways and importance of learning can be exemplified as follows. When cows are introduced to a new area of a barn, it is useful to let the animals get accustomed to this area by their own choice, without forcing by the personnel. To find out that a new area is safe usually requires 2-4 visits. When heifers are to be introduced to the milking parlour the time for them to learn entering the parlour can be reduced if they are given the opportunity to freely investigate the parlour before the beginning of their lactation.

When it comes to milking it is important to have in mind that the motivation for this cannot be expected to be of such predictable nature and such strength as to those for drinking and food intake. Furthermore, the animals within a herd do not act independently of each other, but prefer to act as a coordinated social unit. Usually they rest and eat together. When developing the milking parlour environment this knowledge is of vital significance.

The interaction between the milker and the dairy cow is also a crucial factor in the efficiency of dairy management. Besides the behaviour of the herdsman, interactions such as “hand and arm interaction” and “vocal interaction” between the person and animal are significant when establishing a confiding interaction. It is important for the animals to perceive a positive and safe interaction with the herdsman. Indeed, animals handled aggressively are more fearful of humans and fear is often created by uncertainty.
The herdsman’s behaviour could have direct economical consequences. Indeed, experimental results demonstrate that dairy cows treated with pleasant handling milk more per year. The herdsman’s handling in the parlour during milking (touching of the cows through patting and stroking) can encourage the cows to more easily enter the parlour and exhibit less stress and thereby less inhibition of milk letdown. Also, the use of the voice influences the cow’s production. It has been observed that in the higher yielding herds the herdsman talked to the cows far more often than in the lower yielding herds. Talking “with” instead of talking “to” the animals was associated with high yielding cows.

In many herds today it is not unusual for animals to show different types of more or less abnormal behaviour, such as tongue rolling and bar biting. This could be a result of too little activity for the animals and possibilities to practice their normal behaviour such as search for food. Cows on pasture don’t show oral stereotypes. Feeding more frequently, offering the cows more roughage, and maybe increasing the frequency of milking are examples to reduce these problems.

In conclusion, knowledge about animal behaviour, social interactions and animals psychological requirements are undoubtedly of great importance for high and efficient milk production. Increased knowledge in this area is needed to improve cow traffic to and from the milking parlour and feeding station, teaching the cows to enter the milking robot etc. A better understanding of the animal will undoubtedly influence animal health, animal welfare and production.
The milking machine was developed to reduce the hard work with hand milking. The ancient Egyptians tried to enter tubes into the streak canals to facilitate milking. However, it was not until 1830 the first tube milking machine appeared. Technical development after that would follow. Different types of milking machine principles were tested. Machines imitating hand milking were constructed. The machine that succeeded best was the one based on the suction principle. In 1851 use of vacuum was introduced for the first time and thereafter came the development of the one chamber teat cup. The two chamber teat cup was invented 1905 and a milking machine comparable with the machines of today was presented (Figure 29).

**Biological demands of the milking machine**

What kind of demands do we place on the milking machine? When the first milking machine was developed the demand was defined as efficient milk removal without causing any teat damage as well as being a tool for the farmer to reduce the labour related to milking. In order to fulfill these demands, the development of the milking machine is a multidisciplinary work where biologists, engineers and veterinarians collaborate.

How is the milking machine acting on the teat? The principle of machine milking differs from the principle of hand milking or suckling. During hand milking the milk is pressed out, while during suckling the milk is mainly pressed and to some degree sucked out. During machine milking the milk is sucked out by a difference in pressure between the inner wall of the udder and the liner (Figure 30a, b, c).
If a constant sucking is applied to the teat, blood and lymph would be accumulated in the teat. Therefore the milking machine is constructed so that sucking is interrupted by rhythmical motions (opening and closing) of the liner. Consequently, the teats are exposed to massage and congestion in the teat end is prevented.

All the parts in the milking unit must be treated as vital components in the whole system. For example, what is the importance of constructing a liner with optimal function if the pulsation frequency, vacuum level or dimensions of the milk tubes are inferior. However, for some better understanding of the system let’s briefly discuss the importance and demands of the different components.
**Liner**

The cluster (unit) consists of four teat cups (each having a shell, a flexible liner and a short pulse tube), a claw, a long milk tube and a long pulse tube (Figure 31). The liner consists of a head, a barrel and a short integrated milk tube (Figure 32). The liner is the only part of the milking machine which is in direct contact with the teat. Design of the liner therefore is highly important for optimal milking and teat treatment. Results from comparative experiments show that the liner design usually affects milking characteristics more than any other machine factor. The liner design can influence factors such as strip yield, liner slip, milking time, teat treatment and udder health. Liners must be designed to provide an airtight joint at both ends of the shell, provide a mouthpiece and barrel which will fit on the teat to minimize liner slips and cluster fall off. It must milk fast, as complete as possible, and reduce teat congestion and injury.

On the market there are an enormous number and range of liner designs, which all try to achieve the goals. As an example, the diameter of the mouthpiece lip ranges from 18-27 mm and the bore diameter from 20-28 mm. The reason why the design of the liners varies is mainly due to the variation in teat size and teat configuration among breeds. However, the range of the size within a herd is often greater than the average differences among most herds and breeds.
It is worth noticing that if the liner is too short, the barrel will not have enough space to collapse under the teat leading to inefficient milking, while a too large liner might cause frequent slipping.

Besides different designs of liners, the material of the liner varies. Liners may be manufactured in natural, synthetic or silicone rubber. Natural rubber deteriorates faster due to contact with fat, resulting in shorter life time. Therefore, synthetic rubbers or mixtures of synthetic and natural rubber are more commonly used today.

The liner must be manufactured to withstand extreme stress. It pulses once every second, over 400 000 times per month, at the same time it is stretched as much as 20% or more than its original length. Therefore, regular replacements are recommended to ensure an optimum elasticity of the liner.

Figure 31. Teat cup cluster showing components.
Principally, as soon as the teat enters the open liner it stretches to about 140-150% of its premilking length under the influence of the milking vacuum. During the milking the teat further moves into the liner the very first seconds of milking and no further movement can be detected until the flow ceases in that particular quarter. At the end of milking the liner sometimes crawls up along the teat and thereby obstructs the milk passage from the udder cistern to the teat cistern a phenomenon which in the long run will influence the milk production due to its effect on strip yield. Indeed, several factors influence the depth of the teat penetration. These factors are related to the teat, vacuum, liner, cluster, and friction between liner and teat. Optimal teat penetration is achieved when all these factors work together.

The liner movement during a pulsation cycle results in milk extraction and udder massage. The pulsation cycle can be divided in four different phases a, b, c, and d (Figure 33). During phase a, the opening phase, the liner starts to open resulting in milk extraction and udder massage. The pulsation cycle can be divided in four different phases a, b, c, and d (Figure 33).
in milk flowing from the teat. During phase b, the milking phase, the milk continues to flow. The following phase c, the teat cup liner starts to close and milk is prevented from flowing from the teat. The last phase, d, the massage phase or resting phase, the liner is kept closed.

In order to achieve an optimal milking efficiency and good udder health the rest phase should be at least 15% of the pulsation cycle or 150 ms. The liner wall movement is affected by the milk flow in such a way that high milk flows are related to a shorter massage phase, which in the long run influence udder health. Recent development work has resulted in the so called Harmony® liner, where the massage phase is almost unaffected by the milk flow (Figure 34). The liner movement is also critical during the beginning and at the end of milking when the milk flow is low.

The force exerted by the collapsed liner causes the teat canal to close. In order to overcome the diastolic pressure in the blood vessels a pressure on the teat close to 10 kPa will be recommended in a situation where the pressure difference is about 50 kPa. Besides vacuum and pressure difference the liner plays an important role for massage efficiency. At a lower vacuum a soft and at higher vacuum a more stiff liner is recommended.
It can be concluded that in order to maintain good teat conditions and to create optimal milking performance the liner dimensions have to fit to the cows in the herd and the liner has to be adapted to the installation’s vacuum level and level of the milk line. The liners should be mounted under moderate tension and have a relatively soft mouth-piece. In order to maintain its performance, liner replacement shall take place after 2500 milkings or 6 months in use, whichever comes first. Some types of liners have compounds which have a working life of 1000-1200 milkings.

Figure 34. Liner wall movement in relation to flow.
**Teat cup shell**

The teat cup shells are usually manufactured in stainless steel. However, during the last decades constructions in plastic have appeared on the market. The demands on the shells are a shape to suit the particular liner design, it should be easy to handle during milking, and it should be constructed of material that stands hard handling such as kicking from the cow. In order to optimise the weight of the cluster the weight of the teat cup should be optimised accordingly.

**Claw**

The claw connects the short pulse tube and the short milk tube from the four teat cups to the long pulse and milk tube respectively. Different designs of claws exist on the market with variation in material, milk chamber volume (50-500 ml), air admission hole and “inner” design (Figure 35).

*Figure 35. Different design of claws.*
The demands on the claw are manifold. The flow rates of high producing dairy cows are increasing which means the claw must handle larger amounts of milk. The claw should avoid cross infection among quarters of the same cow. One way of achieving this can be by separate quarter chambers or non-return valves. The air admission to the milk chamber helps to remove milk from the cluster, whereby its size and capacity are critical in milking situations where cows are high yielding and milk very fast.

A good example of a claw that has succeeded to fulfill many demands is the Harmony claw. In this claw the vacuum fluctuations are low even with a high milk flow, since the milk is removed from the bottom through the top of the claw via a central pipe. This means that there is always space left in the claw, which is not filled up with milk ensuring an additional buffer volume for vacuum. Milk is therefore continuously removed from the claw and the extracted milk is gently treated in a way that causes no increase in free fatty acids (FFA).

**Cluster**

The cluster consists of the four shells each including a liner all connected to the claw. The special demands on the cluster as a unit are to have a proper weight to reduce strip yields, slipping and fall off. Increasing cluster weight usually causes reduced strip yield, but increased slipping and falling off. In order to increase cluster weight some manufacturers increase the weight of the claw while others add some weight to the teat cups. The ideal situation is where most weight is put in the teat cups to give more equal weight distribution among the four quarters. However, of all the components in the cluster, the long milk and pulse tubes have the greatest effect on weight distribution, since insufficient tube alignment can cause imbalance in weight distribution.

In the Harmony concept the cluster weight is low, both the teat cups and the claw, improving the ergonomic situation for the milker. Along with this much development work has been done in order to find the best liner function together with a low weight cluster, still having sufficient milking performance. Consideration for a good milking performance has also resulted in increased outlet area for the short milk tube as well as an increase in volume of the short milk tube.
Vacuum and pulsation

How are the machine parameters vacuum, pulsation ratio and pulsation frequency influencing the efficiency of milking? It has been experienced that vacuum levels above 50 kPa show little or no advantage to efficient milking. As can be seen in Figure 36 peak flow rate as well as strip yield increases with increasing vacuum levels. Since the incidence of hyperkeratosis of the external teat orifice and an increase in the degree of machine induced congestion and oedema also follows it is important to find the optimal vacuum level for each individual milking system. For example in low line installations vacuum levels around 42 kPa is comparable to 50 kPa in high line installations. To maintain vacuum stability is of highest interest when it comes to mastitis. Therefore cyclic vacuum fluctuations should be reduced, for example by air admission in the claw, by improving liner design to minimize liner slips and of course by removing teat cups gently at the end of milking. Before removing the teat cups from the udder, the use of a valve for vacuum is essential in order to reduce vacuum fluctuations.

Figure 36. Effect of vacuum level on peak flowrate (solid line) and machine strip- ping yield (broken line). (From Mein, In Machine milking and lactation, ed Bramley et al, 1992).
Pulsation rate and ratio are parameters that also influence milking characteristics such as milk flow and milking time (Table 4). Peak flow rate increases with increasing pulsation rate up to 160 cycles/min depending on the pulsator ratio. As a comparison, it has been reported that the calf uses a frequency of 120 cycles per minute during suckling. If the ratio is elevated to about 80% a fall in peak flow can be observed, probably due to insufficient degree or duration of compressive load on the teat. One recommendation for an effective pulsation is that the liner should be fully closed at least 15% of the pulsation cycle in order to overcome the congestion induced by the milking vacuum. From experiments it can be concluded that optimal pulsation ratio is 60:40 or 70:30 at a pulsation frequency of 60 cycles per minute.

**Ergonomics**

The demands on the milking equipment and milking parlours from an ergonomic point of view must be high, since dairy farming is one of the most burdensome activities within agriculture. High incidences of problems of the locomotor organs are found among dairy farmers. Milk producers often report difficulties in the elbows, lower back, hips knees, hands and hand joints.

The development started with replacing bucket milking plants by pipeline milking plants, which was a tremendous progress for the farmer’s labour situation. Also, during 1970s automatic cluster removers were introduced. Since then development has continued and resulted in a lot of new products. The concept of Harmony includes a cluster with low weight which is easy to handle. Comparing the conventional milking unit and the Harmony®, cluster weight is reduced by more than 40%. The load on the milking operator is reduced and the milking routine time reduced. The concept of DeLaval carrier rail was the next step forward for stanchion barns. DeLaval carrier rail is a rail system that runs from the milk room through the whole stable.

<table>
<thead>
<tr>
<th>Pulsation ratio (%)</th>
<th>40</th>
<th>80</th>
<th>120</th>
<th>160</th>
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</thead>
<tbody>
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<td>50</td>
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<tr>
<td>75</td>
<td>134</td>
<td>142</td>
<td>141</td>
<td>140</td>
</tr>
</tbody>
</table>

* Comparative peak flowrates for a group of cows milked at a vacuum of 51 kPa (15 in Hg). Results are expressed as percentages of peak flowrate obtained at a pulsation rate of 40 cycles/min and pulsation ratio of 50%, i.e. liner more than half open for 50% of each pulsation cycle when tested with the liners stoppered.
In a study performed by the Swedish Farmers Health Service it was found that the use of DeLaval carrier rail reduced the health problems (Figure 37).

In the milking parlour automatic cluster removers are common as well as the “service arm”. Today it is also possible to have a moveable floor (Comfloor) in the parlour, adapted to the height of the milker.
Flow-controlled milking

During development of milking machines it is important to be aware of the nature of the physiology of the milk let down process. As discussed above a good milking machine must empty the udder as efficiently as possible, milk with a proper teat stimulation and not cause damage to the teats. One way to satisfy these demands is to practice flow controlled milking.

During the first seconds of milking as well as during the end of milking the milk flow is low, reaching a value of a few hundred grams of milk per minute. During the high flow phase the milk flow reaches values typically of 3-6 kg milk per minute. The system vacuum level is usually kept at a constant level throughout milking. However, the ideal situation is a milking machine which is adapted to the variation in milk flow during the complete milking and to the different udder quarters. A good example is the DeLaval milking unit MU200D principle, which has a lower vacuum in the beginning and at the end of milking combined with a reduced pulsation speed. Another example is the DeLaval milking unit MU350 principle, where also vacuum levels and pulsations are adjusted to the milk flow. In the DeLaval milking unit MU350, the vacuum level is low, the pulsation frequencies are normally 50 cycles per minute and the ratio is adapted to give a longer massage phase (30:70) during the low flow phase. A flow controlled milking, which is directly "controlled by the cow" results in a more gentle treatment of the teats during the low milk flow. Also a kind of stimulation effect is reached, since the pulsation ratio and frequency are altered during low flow in a way simulating pre and post-stimulation, events which are observed during calf suckling.

DeLaval milking unit MU350

DeLaval milking unit MU350 milker is developed for stanchion barns. As mentioned above the principle of DeLaval milking unit MU350 milker is a flow-controlled milking, including the three different milking phases, pre-milking phase, milking phase and post-milking phase (Figure 38).

During the premilking phase the vacuum level is 33 kPa, pulsation ratio 30:70 with 50 cycles per minute. As soon as the milk flow is above limit (can be chosen between 200, 300 or 400 gr/min) the vacuum level is switched to the high level, pulsation ratio changed and rate too. If the milk flow doesn´t reach the limit for high flow within a certain time, DeLaval milking unit MU350 switches to milking phase automatically. This critical time can be adjusted to the demands from each individual herd. The post milking phase starts when the milk flow is below the preset limit. The length of the post milking phase can vary between five and 30 seconds depending on the predetermined value.
If the high milk flow returns within five seconds DeLaval milking unit MU350 switches back to milking phase. The benefit of this type of controlled milking is a more gentle milking.

The pulsator used in DeLaval milking unit MU350 concept is an electronically controlled pulsator. This kind of device ensures an exact and safe pulsation for a fast milk extraction and good udder health.

DeLaval milking unit MU350 provides the farmer with actual milking data on a display. Information about milking time, milk flow and milk yield is indicated. The data can be used as a tool for feed control and indication of variations in milk yield due to oestrous or disease.

DeLaval milking unit MU350 concept is also provided with a device for good ergonomy. A unique automatic cluster remover has been developed. Instead of a vacuum (remover) cylinder a vacuum controlled motor is used for the automatic removal. This device is easy to handle and carry.

**ALPRO system**

The ALPRO milking system can control the milking according to the DeLaval milking unit MU350 /Delaval milking unit MU200D concept. Milk flow as well as milk yield is measured with the DeLaval milk
meter MM15. The milk meter is an electronic meter, which received official ICAR (International Committee for Animal Recording) approval in 1990. The DeLaval milk meter MM15 milk meter and the automatic identification system are two of the basic components for ALPRO system.

The great benefits with the ALPRO system are its unique possibilities for a complete management system (Figure 39).

Farmers have the possibility to collect data from each individual milking and from these data adapt the feeding of concentrate for each individual cow. Furthermore, it is possible through the identification system to control feed consumption. The ALPRO system is a tool for a complete herd management.
Harmony unit

The Harmony cluster (unit) was developed in order to find a liner that would allow a significant reduction of the total weight of the milking cluster, and subsequently, to improve the working conditions for the milkers. Demands were also placed on improved milking performance and teat treatment. The result was a cluster with reduced weight of 43%, where the teat treatment and the vacuum stability beneath the teat were improved and the risks for cross contamination reduced. The development work with such a milking unit succeeded in implementing all factors improving milking performance, ergonomics and udder health (Figure 40). The Harmony milking units are also used in the DeLaval milking unit and ALPRO Systems.

Figure 40. Harmony® the milking cluster with unique features.
Automatic milking

One of the most labour intensive and time consuming jobs in dairy milk production is milking. Besides that, milking has to take place at least twice a day all year around. Demand has been growing for an automated milking system to solve this problem.

An automatic milking system includes a lot of different management concepts such as cow identification, measuring the milk yield, milk flow and milking time, by different sensors measure deviations in milk composition and automatic attachment and removal of the cluster. The milking can take place during all 24 hours, with a break for cleaning. The system also allows the cow to be milked as often as she wants (Figure 41).

Automatic or robotic milking is a system with advantages directly related to the milking technique. It is possible to create a more adapted milking system, a system which is adapted to the four individual udder quarters. It is well known that each quarter has rather individual milk flow curves, individual milking times and flow rates. In order to create an optimal milking situation consideration has to be given to the different quarters.
Today there are different companies and institutes working with robotic milking, each company having its specific solution for attachment of the cluster, cleaning the teats and cow traffic. The milking robot has been introduced to some farms. However the development of both hardware and software is still going on.

**Cow status monitoring**

The milking session has always served as a good opportunity for observing the cow with respect to udder health, milk quality and cow behaviour. With increasing automation during milking the farmer doesn’t have this possibility, and therefore needs technical solutions and reliable tools to support the so called “cow eye”. Furthermore, the demand on the milk quality is increasing both with respect to composition and residues. Development of sensors for direct online measurements of the milk during milking as well as sensors and measuring instruments for analysing bulk milk are in progress.

The sensors mostly discussed today are those intended for detecting mastitis. A sensor measuring the electrical conductivity in the milk has been evaluated. Difference in the electrical conductivity is used as a signal for mastitis. Another “sensor” for detecting oestrous is an activity monitor, which records the activity of the cow and from the obtained data calculate differences which could be transformed into data signaling oestrous. The developments of these sensors and the associated computer software models are in progress.

**Epilogue**

In this booklet we have discussed milking from a biological point of view. The subject is quite big and unfortunately we have just touched this fascinating area. There are still many problems to solve and unanswered questions to answer, which will keep the research work going on world wide for years to come. A continuing dialogue between scientists, manufacturers and dairy farmers is not only one way to keep the work in progress, it is the way!!
LITERATURE


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