Dairying in KwaZulu-Natal

THE COW'S UDDER AND MILK SECRETION

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The cow's udder consists of four entirely separate quarters (Figure 1). The right and left halves are separated by a distinct membranous wall called the medial (central) suspensory ligament (Figure 2). This ligament is composed of strong elastic tissue that extends between the halves of the udder. Numerous branches (lamellae) extend from this ligament into the quarters. As the udder fills with milk it expands or stretches like a balloon, thereby making room for the milk being stored in the udder between milkings.

The elasticity of the central ligament results in the ungainly and uncomfortable appearance of the udder in high-yielding cows. Not only does the udder force the cow's hind legs apart, making walking difficult, but the middle of the udder drops further from the body than do the outer portions, thus causing milk-engorged teats to project outwards. If the central udder support is weak, then the udder will become pendulous and the teats will face outwards, causing not only difficult milking, but also increasing their susceptibility to injury and contamination by dirt and bacteria.

Figure 1. Sub-division of the udder into left and right halves and front and rear quarters (Quinn, 1990)

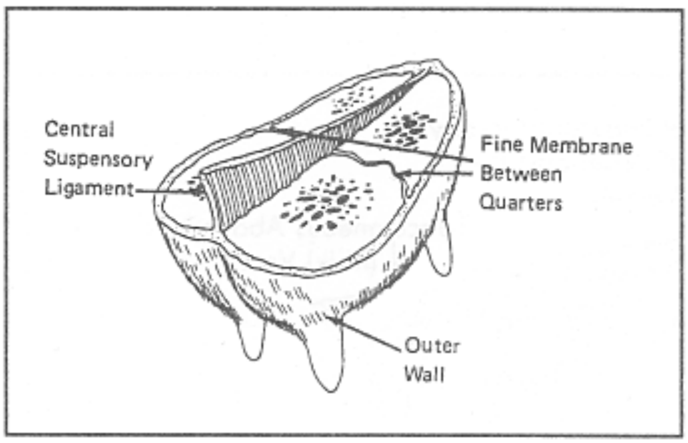
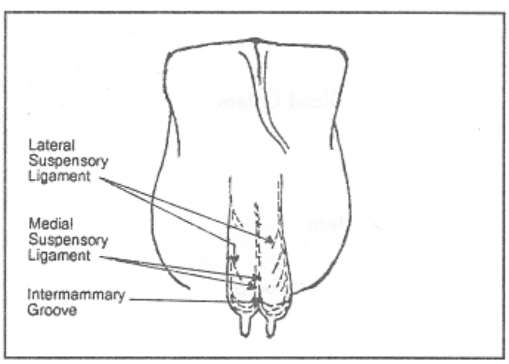


Figure 2. Support the udder (Frandson, 1986)



The front and rear quarters of the udder are divided by a very thin wall of connective tissue which is irregular in outline. This division is difficult to see from the outside.

The outer wall of the udder contains ligaments which blend into muscles in the hind quarters of the cow. The milk-secreting parts of the udder are supported by web-like connective tissue which cris-crosses the udder (see Figure 3). Some cows may have large udders, not because they are high producers, but because of a high content of connective tissue. This allows less space for milk-secreting tissue. Udders which shrink noticeably and become flabby after milking contain little connective or scar tissue.

Each of the four quarters contains a seperate mammary gland (Figure 3) which, in turn is composed of:-

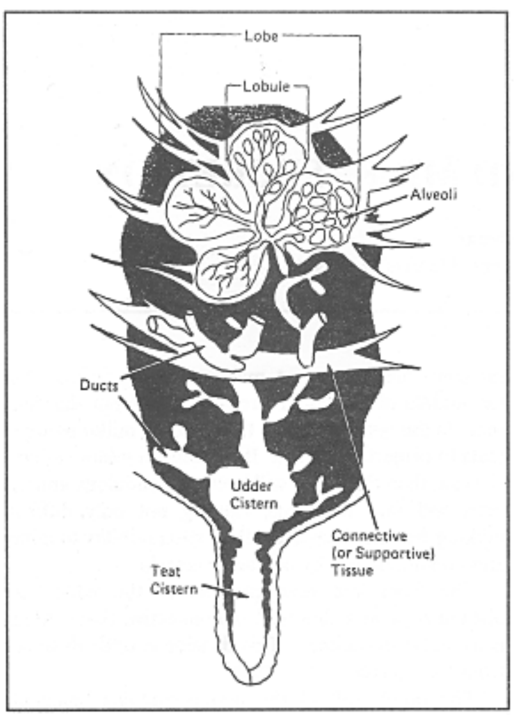
Secretory tissue (alveoli)
A duct system (interconnecting tubes)
Two cisterns (storage areas)
A teat

THE TEATS

Milk is removed from each gland by the streak or teat canal which is 8 to 12 mm long (Figure 4). It is kept closed between milkings by a circular sphincter muscle near the tip. This muscle is important not only in keeping the milk in the gland, but also in preventing entry by bacteria.

The character of the sphincter is important to the cow's productivity. If the canal is small, or if the sphincter is unusually strong, then the cow is hard and slow to milk. At the opposite extreme (large canal, or weak sphincter), milk will leak from the teat between milkings and the udder is then open to invasion by mastitis-causing organisms.

Figure 3. Components of the udder (Quinn, 1980)



Teat cistern

This cavity of the teat, located just above the streak canal (Figure 3), stores the milk which drains from the gland. It normally holds 15 to 40 ml of milk, depending on the size of the teat.

Blood supply

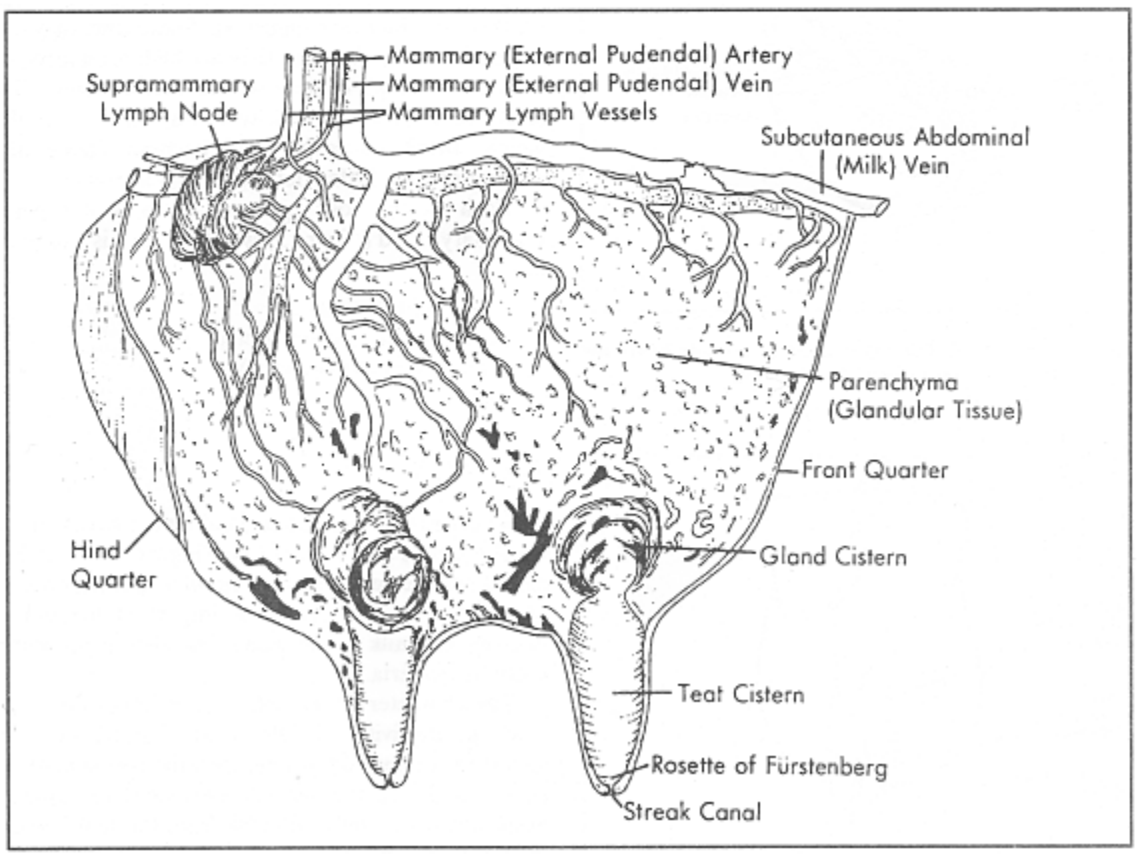
The teat contains many blood vessels with small valves that maintain blood flow when the teat is massaged (by the teat cup liner). Lack of massage during milking causes blood and other body fluids to dam-up in the teat. This is painful to the cow, and she will then be inclined to kick.

GLAND CISTERN

The gland, or udder, cistern is located just above the teat cistern (Figure 4) and is partially separated from it by annular folds of tissue. Although the udder cistern varies in shape and size between quarters and cows, it stores only about 500 ml of milk.

The annular folds can become the cause of milking problems if the teat cup of the milking machine is allowed to creep up toward the udder. This pinches the annular fold and stops the flow of milk (Figure 5). Creeping also causes irritation to the sensitive tissue of the udder and can be the cause of injury or mastitis.

Figure 4. Components of udder showing blood supply (Frandson, 1986)



DUCTS

A number of large ducts (tubes) branch off from the gland cistern. These ducts branch and re-branch into smaller and smaller ducts (similar to roots of a tree) and finally into the small ductules that drain each alveolus (Figure 6).

The function of the duct system is to collect the milk from the secretory tissue, to store part of the milk between milkings and to transport the milk to the gland cistern.

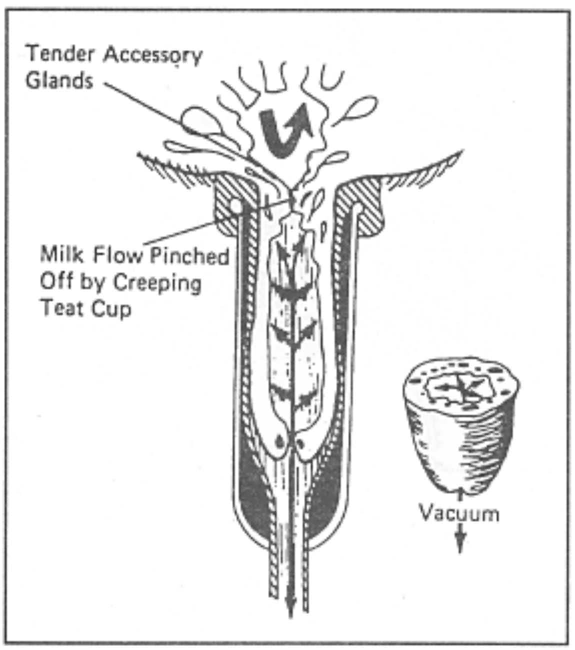
Where the milk ducts branch-off from a larger duct, a narrowing of the tube occurs. As the lobules (milk secreting glands) fill up with milk, their weight causes them to sag downwards (Figure 7). This causes the narrow branch of each duct to be pinched and close. Consequently, milk does not drain from the udder until the cow is stimulated to let-down her milk.

SECRETORY TISSUE

The main milk-producing unit is the alveolus. This is a microscopic structure, almost spherical in shape, the outer surface of which is lined with a single layer of epithelial (milk-secretory) cells and has a tiny duct to allow the milk to drain out (Figure 8). The alveolus thus resembles a grape with its stalk. The outer layer also contains a complex of tiny, muscle-like cells called myoepithelial cells.

The alveoli are connected by small ducts, and groups of alveoli form lobules. A group of lobules, in turn, forms the main lobe of each quarter (Figure 3). The udder of the dairy cow contains about 5×10^{12} secretory cells in the epithelium of the alveolar tissue.

Figure 5. Teat cups that are allowed to creep tend to pinch off the opening and stop the milk flow (Quinn, 1980)



These have a short life and are rapidly replaced. In early lactation there is a net gain in cell numbers, but after peak yield there is a gradual decline in total numbers. Each alveolus is surrounded by a network of minute blood vessels (capillaries which carry the substances from which milk is synthesized.

When the hollow part of the alveolus is filled with milk, these small muscles expand to their fullest length. During milking the muscles contract and squeeze the milk out of the alveolus.

MILK SECRETION

Source of milk constituents

Although the site of milk synthesis is the epithelial cells lining the alveoli, some milk components (vitamins, minerals, certain proteins) are not synthesized here. They are simply filtered out from the blood, through the cells into the milk. Lactose (milk sugar), fat (butterfat), and most of the proteins (mainly casein) are formed in the epithelial cells from substrates carried in the blood. More than 300 kg of blood must pass through the udder to produce 1 R of milk.

The substrates are filtered from the blood and pass into each epithelial cell (lining the alveolus) through the plasma membrane. When this membrane functions normally, it is extremely selective as to which substances can pass through. However, when the udder is infected (for example, as in mastitis), the selectivity breaks down, and higher levels of blood protein and even white blood cells gain entry to the alveolus.

Figure 6. Constrictions at each branch of the duct system prevent milk from leaking into the teat and lower udder as fast as it is manufactured

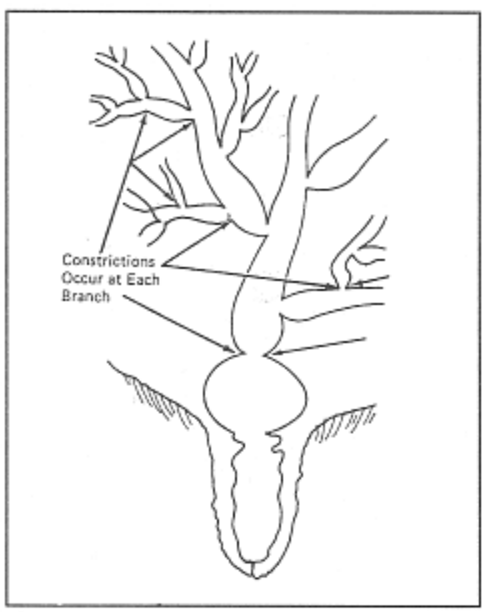


Figure 7. As they fill with milk, the lobes sag with extra weight and pinch off the ducts, thus preventing further flow of milk into the ducts (Quinn, 1980)

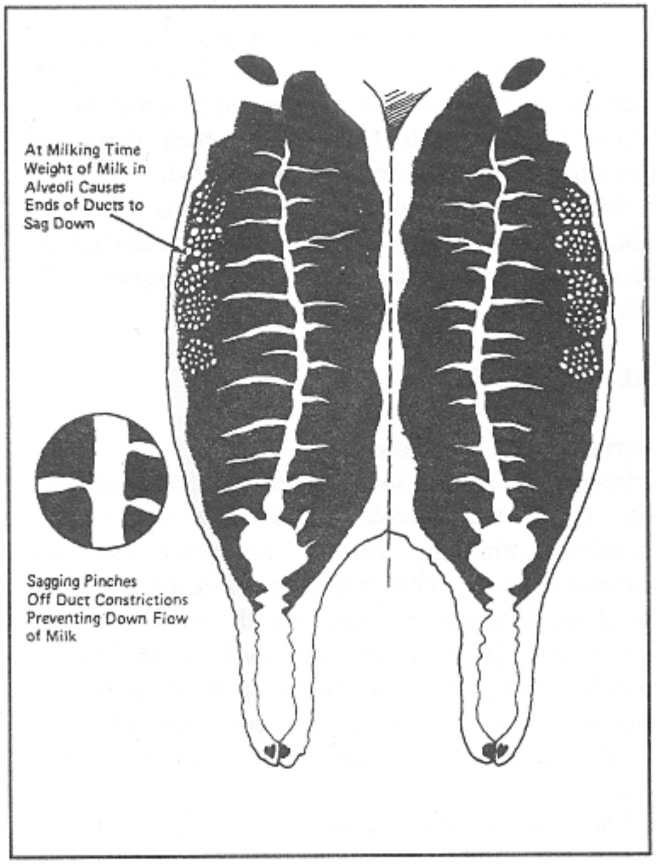


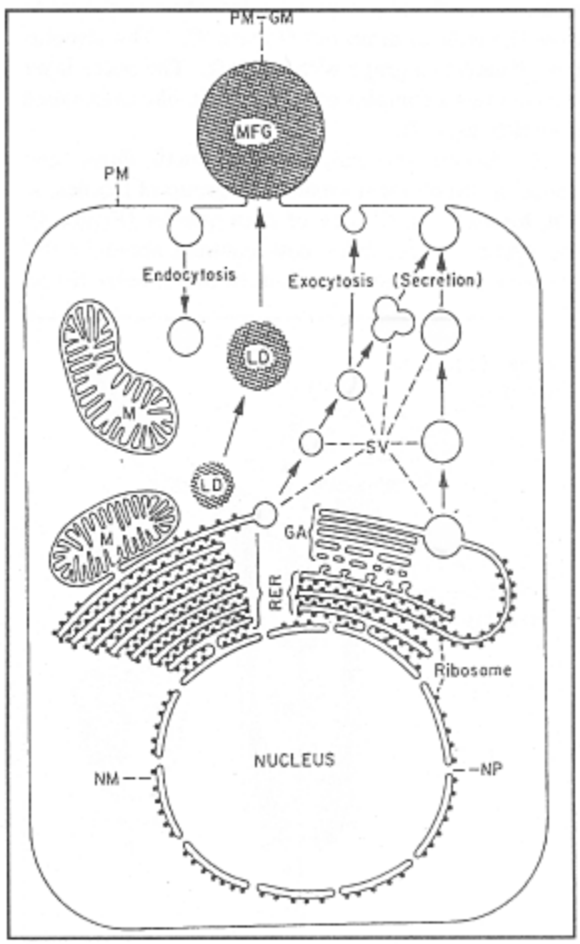
Figure 8. Structure of the alveolus showing: (a) blood capilliary supply: (b) myoepithelial cells: and (c) lumen epithelium of secretory cells lying upon a basal membrane (Whittemore, 1980)

Release into alveolar lumen

The processes whereby milk constituents (fat, protein *etc*) are released from the epithelial cells into the cavity (lumen) of the alveolus are most fascinating. Within the epithelial cell, milk fat is produced as small, well-defined droplets. The droplets enlarge by merging together as they move toward the central lumen of the alveolus. As the fat droplet emerges from the cell it becomes totally surrounded by part of the cell wall, and an actual break or rupture in the lining forms as the fat droplet is pinched-off (Figure 9)

Casein and lactose are also gathered together in small packages (secretory vesicles) surrounded by a membrane. As in the case of fats, these vesicles move towards the lumen of the alveolus. When the vesicle reaches the membrane lining of the epithelial cell, its outer lining fuses with that of the cell. The contents are then discharged into the alveolar cavity.

Figure 9. Schematic diagram of a mammary secretory cell showing the components of a functionally continuous endomembrane system (Keeanan *et al.*, 1974)



Abbr: MFG = milk fat globule; SV = secretory vesicle

This fusion of vesicle membrane and cell membrane repairs the loss caused by escape of fat droplets. Each epithelial cell may discharge fat or protein and casein 15 to 20 times between milkings.

The molecules of proteins, milk sugar, vitamins, and minerals are uniformally distributed within the water of the milk. In contrast, the milk fat globules float in the water after entering the lumen of the alveolus. These fat droplets then collect as tiny clusters which cannot easily pass through the tiny ducts draining the alveoli. However, the water and its contents move freely along the tubes and gradually fill the cisterns of the quarters. Some of the fat is even retained within the secretory cell and will escape only when the pressure within the udder drops during milking. Consequently the first batch of milk removed from the udder contains only 1 to 2% fat while that coming out of the alveoli may reach 24% fat.

Secretion rate

The rate at which epithelial cells manufacture milk is high for the first 10 hours after milking. It then starts to decrease at a rapid rate, and if the cow is not milked it will cease about 35 hours after the last milking. The milk secretory process stops when the pressure inside the alveolus becomes prohibitive. This probably occurs because the pressure constricts the blood vessels, and stops the flow to the milk secreting cells.

Lower-producing cows are LESS adversely affected by long intervals between milkings because lower-producing cows have less secretory tissue in the udder. Consequently, the increase in udder pressure (between milkings) per unit milk is greater in younger and lower-producing cows. Short milking intervals are thus important for young cows. Incomplete milking (*e.g*. leaving 2 kg milk in the udder at each milking) causes a permanent depression in milk production.

Frequency of milking

The rate at which milk is secreted is important in determining how much extra milk will be produced when cows are milked more often than twice daily. On the average, production will be increased by 20% when milking 3 times per day as compared with twice daily. Milking 4 times per day yields a further 5 to 10% increase.

The additional yield occurs because :-

- the milk secreting cells operate at full capacity for longer,
- of better feeding and management often associated with 3 times per day milking.

Decreasing the number of milkings per day causes a marked reduction in milk yield. Skipping one milking a week reduces total yield by 5 to 10%, while milking once daily cuts the yield by half in first calvers, and by 40% in older cows.

MILK REMOVAL

A vital part of lactation is of course the process by which the milk is removed. This includes :-

- passive withdrawal from the cisterns and ducts of the udder
- ejection of milk from the alveolar lumen.

To assist in expulsion of milk from the udder, the myoepithelial cells are arranged in two ways.

- In a starlike (stellate) fashion around the alveoli to achieve a squeezing action and to collapse it. This is called implosion.
- In a longitudinal (lengthwise) arrangement along the small ducts to effect a shortening and widening of these small tubes. This aids the expulsion of the milk from the collapsed alveolus by increasing the size of the passage through which the milk must pass.

These myoepithelial cells have no nerve connection and are controlled by hormones.

In contrast to the myoepithelial cells within the udder, smooth muscle occurs around :

- blood vessels
- small and large ducts
- sinuses

This smooth muscle is controlled by nerves which pass from the spinal column through the glandular tissues terminating at the muscles of the teat sphincter.

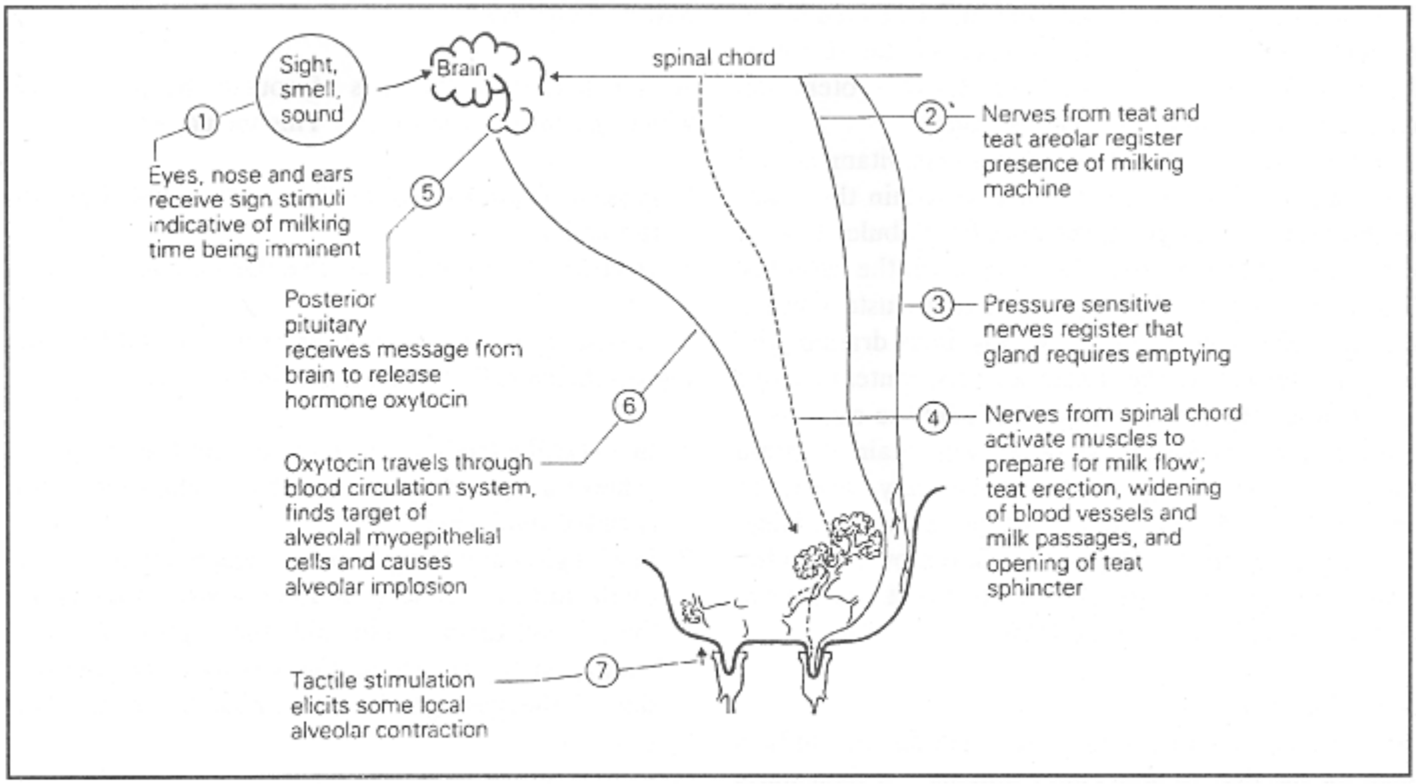
Passive withdrawal

In this phase of milking the active co-operation of the cow is NOT required. Nerve endings in the skin of the udder and of the teat are stimulated by washing/wiping of the udder, the slipping-on of the teat cups and by pressure of the teat liner on the walls of the teat. The teat sphincter at the tip of the teat then opens and milk begins to pass out into the milk tube. This phase, which is activated by the nerves, begins about 5 to 10 seconds after the udder and teats have been stimulated. The nervous reflex brings about a squeezing of the ducts by the smooth muscle and the milk within the ducts is pushed into the udder cisterns. Since the dairy cow has a relatively large cistern, 40 to 50% of the total milk yield may be obtained during this passive withdrawal phase.

Milk ejection reflex

Whilst passive withdrawal of milk in the cisterns is taking place, nerve impulses pass from the teat to the brain in response to stimulation from attaching the milking machine (Figure 10). Other messages picked up via the cow's nose and eyes are also transmitted to the brain by nerves. This information causes the brain to release the hormone oxytocin into the bloodstream. Eventually the oxytocin reaches the udder where it causes the myoepithelial cells around the alveoli to contract. Upon contraction of the myoepithelial cells, the alveoli collapse and milk is squeezed out into the small ducts (Figure 11). These ducts shorten and widen, and the milk rushes through into the gland cistern. Only alveolar and ductal milk is expelled by the action of oxytocin on the myoepithelium. There is no contraction of large ducts or cisterns.

Figure 10. The milk ejection reflex (Whittemore, 1980)



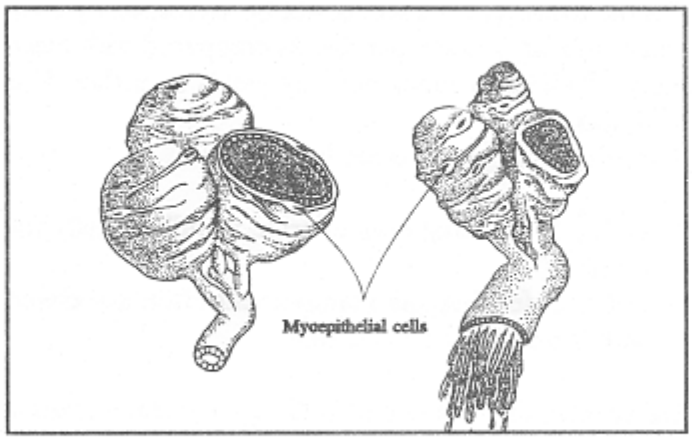
This milk ejection reflex is pre-programmed (*i.e.* conditioned) by the brain. In other words, the brain interprets certain stimuli to mean that milking is about to commence. Accordingly, when the brain receives the correct message it automatically proceeds to trigger the release of oxytocin. The conditioned stimuli for milk ejection include rattling of the milk buckets, washing of udders, feeding of concentrate, approach of the milker, and application of the milking machine or massage of the udder prior to application of the teat cups.

An effective milk ejection reflex is needed to achieve fast, efficient milking. It is vital that the cow is able to recognize the signal from which she can anticipate milking to commence within a relatively fixed time, in other words, the signal must be clear and should always occur at a set time before the machine starts milking.

The milk ejection reflex usually takes place 20 to 40 seconds after the initial stimulation (*e.g.* udder wiping) and lasts for only about 6 minutes (Figure 12). It is most important that the milk is removed while this reflex is operating. The udder should be handled no earlier than 30 seconds before teat cup application, otherwise the beneficial effects of good milk ejection will be lost. In many situations, application of the teat cups themselves is THE stimulation for milk ejection. There will, of course, be 30 to 60 seconds lag between applying the machine and contraction of the alveoli. However, passive withdrawal will be occurring during this interval. This kind of lag may be particularly beneficial when milking high-producing cows since the reduction of pressure within the cisterns (by passive withdrawal) will aid flow from the alveoli. Once the effect of oxytocin wears off, milk that has not been removed will flow back from the udder sinuses into the ducts and eventually into the alveoli. It can then be removed only after oxytocin has again been released, which will probably occur only at the next milking. The extra pressure within the udder will reduce the synthesis of milk after the incomplete milking, and ifthis situation occurs repeatedly the cow will reduce her yield accordingly. In dairy cows the milk ejection reflex is probably essential for 50 to 60% of the total yield at a milking.

It is thus vital to capitalize rapidly and effectively on the cow which has been properly stimulated and to remove all the milk as soon as it becomes available. Effective emptying of the udder is thus an essential component of successful parlour routine.

Figure 11. Milk ejection - the contraction of the myoepithelial cells surrounding the alveolus forces milk out of the lumen into the ducts (Schmidt, 1971)

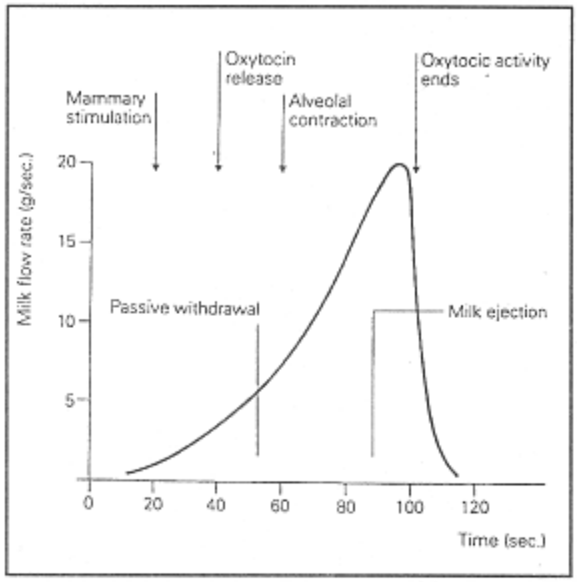


Inhibition of milk let-down

The milk let-down reflex of cows is very easily retarded or prevented by external stimuli which disrupt the NORMAL routine for milking. It is often said that a cow "holds up" her milk. This is NOT possible since the cow has no voluntary control over the let-down process, and she cannot thus put the process into REVERSE. However, let-down can be prevented, or terminated, by nervous stimuli such as rough treatment of the cow, loud, unfamiliar noise, pain and irritation. Such stimuli cause the brain to release adrenalin. This hormone works against oxytocin by:

- blocking oxytocin release from the brain
- constricting blood vessels and preventing oxytocin from reaching the udder
- directly counteracting the effect of oxytocin on the contraction of myoepithelial cells.

Figure 12. Pattern of milk flow from the udder (Whittemore, 1980)



If adrenalin release occurs before the milk-ejection stimulus, the ejection will be virtually completely blocked. When adrenalin is released after milk ejection has commenced, it will result in large amounts of milk being retained in the udder with associated negative effects on milk yield.

Cows handled gently and milked carefully at regular intervals seldom suffer from this problem. Milking should be a pleasant experience for the cow in order to capitalise fully on milk ejection.

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