**Babcock Institute for International Dairy Research and Development**

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**Dairy Essentials**

# 20) MILK SECRETION IN THE UDDER OF A DAIRY COW

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## MAMMARY GLAND STRUCTURE

The udder of a cow is an organ designed to produce and offer a newborn calf easy access to its mother's milk. It is suspended outside the wall of the rear abdomen and thus it is not restrained, supported, or protected by any skeletal structures.

The udder of a cow is made up of four mammary glands or "quarters." Each quarter is a functioning entity of its own which operates independently and delivers the milk through its own teat. Generally, the rear quarters are slightly more developed and produce more milk (60%) than the front quarters (40%). The major components of the udder are listed here with a short explanation of their importance and function.

**Support system**. A set of ligaments and connective tissue maintain the udder close to the body wall. Strong ligaments are desirable because they help to prevent the occurrence of pendulous udder, minimize the risk of injuries, and avoid difficulties when using milking equipment.

**Secretory and duct system.** The udder is known as an exocrine gland because milk is synthesized in specialized cells grouped in alveoli, and then is excreted outside the body through a duct system that functions like the tributaries of a river.

**Blood supply and capillary structures**. Milk production demands a lot of nutrients that are brought to the udder by the blood. To produce 1 kg of milk, 400 to 500 kg of blood must pass through the udder. In addition, the blood carries hormones that control udder development, milk synthesis, and the regeneration of the secretory cells between lactations (during the dry period).

**Lymph system.** Lymph is a clear fluid that comes from tissues highly irrigated by blood. The lymph helps to balance the fluid flowing in and out of the udder and helps to combat infections. Sometimes the increased blood flow at the onset of lactation leads to an accumulation of fluid in the udder until the lymph system is able to remove the extra fluid. This condition, referred to as udder edema, is more

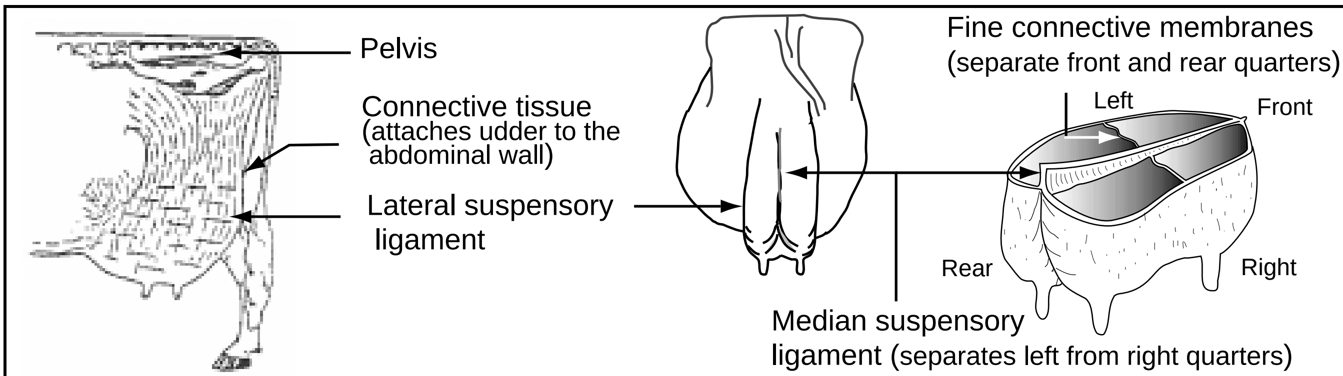


Figure 1: The support system of a cow's udder

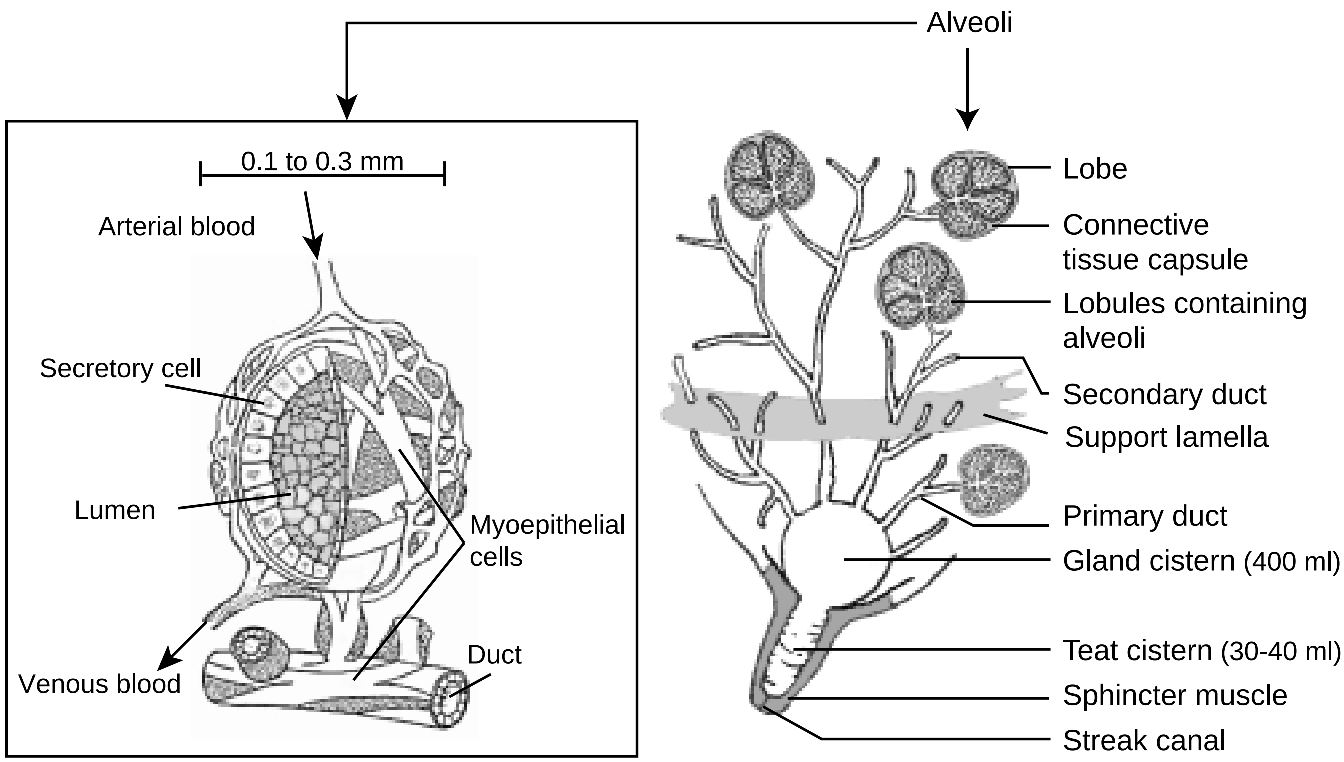


Figure 2: Alveoli and ducts form the milk secretory system

prevalent in first-calf heifers and older cows with pendulous udders.

**Innervation of the udder.** Nerve receptors on the surface of the udder are sensitive to touch and temperature. During the preparation of the udder for milking, these nerves are triggered and initiate the "milk let down" reflex that allows the release of milk. Hormones and the nervous system are also involved in the regulation of blood flow to the udder. For example, when a cow is startled or feels physical pain, the concerted action of adrenaline and the nervous system decreases blood flow to the udder, inhibits the "milk let down" reflex and lowers milk production.

### Support system

In modern dairy cows, the udder may weigh more than 50 kg because of the large amount of secretory tissue and milk that accumulates between milkings. The main structures that support the udder are the median suspensory ligament and the lateral suspensory ligament (Figure 1). The skin also plays a minor role in the support and stabilization of the udder.

The median suspensory ligament is an elastic tissue that attaches the udder to the abdominal wall. Viewed from behind, the inter-mammary groove, a distinct mid-line groove in the udder, marks the position of the median suspensory ligament. Because this tissue is elastic, it acts as a shock absorber and accommodates changes in the size and weight of the udder that occur with milk production and age. Damage or weakness of the this ligament cause the udder to stretch downward, making it more difficult to milk and increasing the likelihood of injuries, especially to the teats. Genetic selection for a strong suspensory ligament is effective in minimizing these problems in the herd.

In contrast to the suspensory ligament, the lateral suspensory ligament is a rather inflexible fibrous tissue. It reaches down the sides of the udder from the tendons around the pubic bones to form a sling.

### Duct and milk secretory systems

The alveolus is a functional unit of production in which a single layer of milk secretory cells are grouped in a sphere with a hollow center (Figure 2). Capillary blood vessels and myoepithelial cells (muscle-like cells) surround the alveolus, and the secreted milk is found in the internal cavity (lumen). The functions of the alveolus are:

- To remove nutrients from the blood;
- To transform these nutrients into milk;
- To discharge the milk into the lumen.

The milk leaves the lumen through a collecting duct. A lobule is a group of 10 to 100 alveoli drained by a common duct. Lobules are themselves organized into a larger units called lobes. The lobes discharge the milk into larger collection ducts that lead to the gland cistern, which lies directly above the teat of the gland (Figure 2).

The udder is thus composed of billions of alveoli where milk is secreted. The ducts form channels of drainage in which milk accumulates between milking. However, it is only when the myoepithelial cells that line the alveoli and the smaller ducts contract in response to the hormone oxytocin (milk let-down reflex) that milk flows into the galactophores and the gland cistern.

The teat forms a passageway through which the milk can be withdraw from the gland. It has a smooth skin covering and a rich blood and nerve supply. The teat tip closes with a smooth muscle ring or sphincter called the “streak canal.” At its upper end, the teat is separated from the gland cistern by only a series of delicate folds of sensitive cells particularly vulnerable to damage. These folds of tissue are also found at the other extremity of the teat directly above the streak canal (rosette of Furstenburg). The teat is thus designed as a effective barrier to invading bacteria. Preservation of the normal teat structure is essential to the maintenance of the natural defense mechanism against mastitis-causing bacteria. Differences in teat structures, particularly the diameter and the length, are related to susceptibility to infection.

## MILK SECRETION IN THE SECRETORY CELLS

Milk secretion by the secretory cells is a continuous process that involves many intricate biochemical reactions. During milking, the rate of milk secretion is somewhat depressed, but it never stops completely. Between milkings, the accumulation of milk increases the pressure in the alveoli and slows down the rate of milk synthesis. As a result, it is recommended that high-producing cows be milked as close as possible to 12 hour intervals (the highest milkers should be milked first in the morning and last in the evening). More frequent ejection of milk reduces the pressure build-up in the udder, and for this reason milking three times a day can increase milk yield by 10 to 15%.

The secretory cell is a complex factory. Figure 3 presents a summary of the

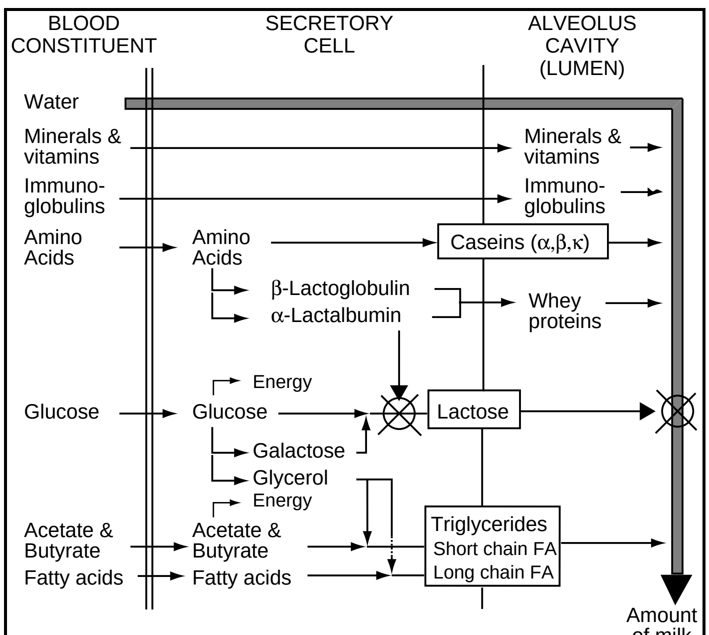


Figure 3: Overview of milk secretion in the secretory cells (crossed circles are key regulatory steps).

mechanisms and the origin of nutrients needed for milk synthesis.

**The use of glucose by a secretory cell.** Although glucose in the diet is entirely fermented in the rumen in volatile fatty acids (acetic, propionic and butyric acids), it is needed in large amounts by the lactating udder. The liver transforms propionic acid back into glucose which is transported by the blood to the udder where it is taken up by the secretory cells. Glucose can be used as a source of energy to the cells, as the building block of galactose and subsequently lactose, or as the source of the glycerol needed for the synthesis of fat.

**Synthesis of lactose.** The synthesis of lactose is controlled by a two-unit enzyme called lactose synthetase. The sub-unit α-Lactalbumin is found in the milk as a whey protein.

**Regulation of milk volume.** The amount of milk produced is controlled primarily by the amount of lactose synthesized by the udder. Lactose secretion into the cavity of an alveolus increases the concentration of dissolved substances (osmotic pressure) relative to the other side of the secretory cells where the blood flows. As a result, the concentration of dissolved substances on each side of the secretory cells is balanced by drawing water from the blood and mixing with the other milk components found in the cavity of the alveolus. For normal milk, a balance is reached when there is 4.5 to 5% lactose in the milk. Thus lactose production acts as a "valve" that regulates the amount of water drawn into the alveoli and therefore the volume of milk produced (crossed circles in Figure 3).

The effect of the diet on milk production may be easily seen:

1) The amount of energy (i.e., concentrates) in the diet influences propionate production in the rumen;
2) The propionate available influences the amount of glucose synthesized by the liver;
3) The glucose available influences the amount of lactose synthesized in the mammary gland;
4) The lactose available influences the amount of milk produced per day.

**Synthesis of protein.** The caseins found in the milk are synthesized from the amino acids taken up from the blood under the control of the genetic material (DNA). These proteins are packed in micelles before they are released in the lumen of the alveolus. Genetic control of milk synthesis in the alveoli comes from the amount of α-Lactalbumin synthesized by the secretory cells. As described above, this enzyme is an important regulator of the amount of lactose and milk produced per day.

The immunoglobulins are synthesized by the immune system, and these usually large proteins are drawn from the blood into the milk. The permeability of the secretory cells to immunoglobulins is high during the synthesis of colostrum, but decreases sharply with the onset of lactation.

**Synthesis of fat.** Acetate and butyrate produced in the rumen are used, in part, as the building blocks of the short-chain fatty acids found in milk. The glycerol needed to "unite" three fatty acids into a triglyceride comes from glucose. About 17-45% of the fat in the milk is built from acetate and 8-25% from butyrate. Diet composition has a strong influence on milk fat concentration. Lack of fiber depresses the formation of acetate in the rumen, which in turn results in the production of milk with a depressed concentration of fat (2-2.5%).

Lipids mobilized from body reserves in early lactation are another building block for milk fat synthesis. However, in general, only half the amount of fatty acids in milk fat is synthesized in the udder, the other half comes from the predominantly long-chain fatty acids found in the diet. Thus milk fat composition may be altered by manipulating the type of fat in the cow's diet.