

Physiology of Lactation and Machine Milking

Alen Džidić

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Summary

The main purpose of this article is to describe interaction between physiology of lactation and milking machine. This is important in order to avoid bad influences (such as: high somatic cell count (SCC), mastitis, etc.). The paper is divided into two parts: The anatomy part describes udder characteristics needed for healthy udder and high milk yield. The milking machine part describes milking machine parameters needed for good and easy milking. The main conclusions on udder physiology and milking machine interaction showed that the most important good milking machine routine, regular cow hygiene, regular cow mastitis control, milking pleasant to the cows and presence of three most important hormones (oxytocine, prolactin and growth hormone) for lactation.

Key words: udder anatomy, milk components, milk secretion, milking machine

Introduction

A precondition of good understanding of what is needed to prevent and reduce harmful influences (such as: high somatic cells count (SCC), mastitis etc.) on cow's udder health, is understanding the anatomy of the udder and physiology of lactation. Therefore, the first step will be to understand the anatomy of the cow's udder. Furthermore it is necessary to know the milk components, factors influencing their production synthesis and regulation. Milking machines play the final role in this system; simulating milk let-down. To keep cows udder healthy and to withdraw the highest amount of milk, good milking machine procedure is needed.

Aim

The aim of this paper is to describe the interaction between physiology of lactation and milking machines in order to maintain healthy udder and higher milk yield.

Anatomy of the udder

Udder anatomy can be divided into the exterior and interior anatomy of the udder.

a) Exterior of the udder

The udder of a cow is an organ essential for a newborn calf, as it provides an easy access to mother's milk. The milk capacity of the udder of a high-producing cow post partum can vary from 22.4 kg (29 weeks post partum) to 29.4 kg (0 weeks post partum) (Gibb et al. 1992). It is divided into four quarters. The rear quarters are usually larger than the fore quarters. In these quarters there are between 25 to 50 per cent more secretory tissues than in the fore quarters (Filipović et al., 1934; Lush, 1943).

The udder consists of secretory and connective tissue. Udders, which contain a large amount of secretory tissue and a small amount of connective tissue, are less shapely than udders with a relatively large amount of connective tissue (Espe, 1948).

a) Interior of the udder

The support system of the udder consists of the median and lateral suspensory ligaments. They separate left from right quarters (Figure 1). Median suspensory ligament is made up of two sheets of dense connective tissue (Schmidt, 1971). Median suspensory ligaments are made of elastic tissue and therefore it can stretch downward. If this happens too extreme it can cause difficulties in milking and also may cause damage to the teats. Lateral suspensory ligaments are made from inflexible fibrous tissue. The skin plays a minor role in udder support system.

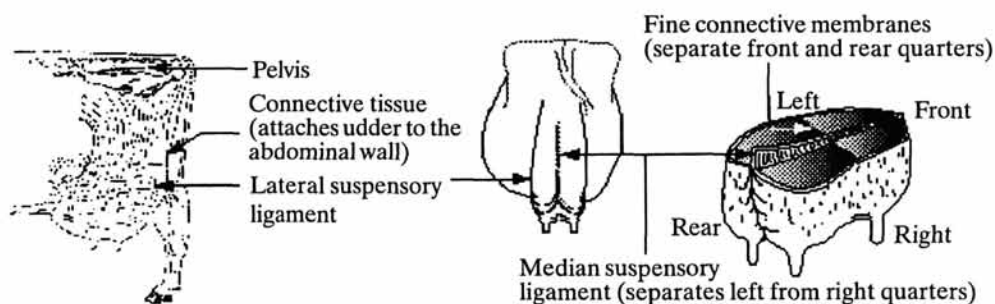


Figure 1: The support system of a cows udder (Wattiaux, 1996)

Slika 1: Sustav građe vimena (Wattiaux, 1996)

The secretory tissue consists of specialized epithelial cells that are synthesizing milk from the substances absorbed from the blood (Mephram, 1976). The secretory tissue is made up of alveoli (Figures 2 and 3).

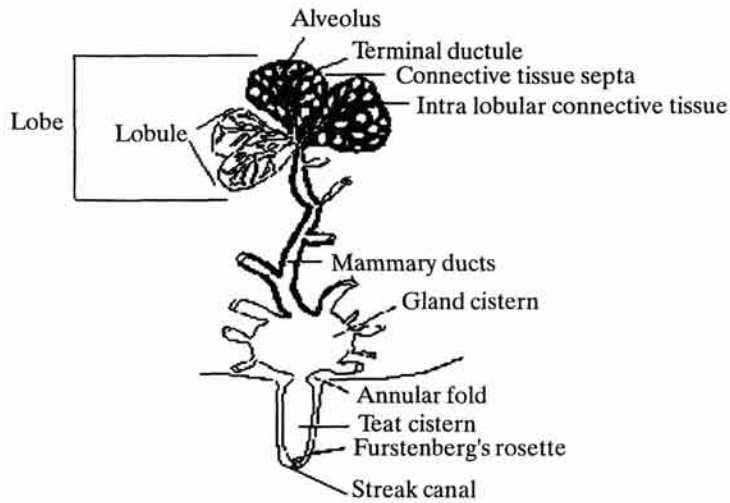


Figure 2: Mammary duct and lobule-alveolar systems (Kennelly, 1998)
 Slika 2: Sustav sisnih kanala i alveolarnih režnjeva (Kennelly, 1998.)

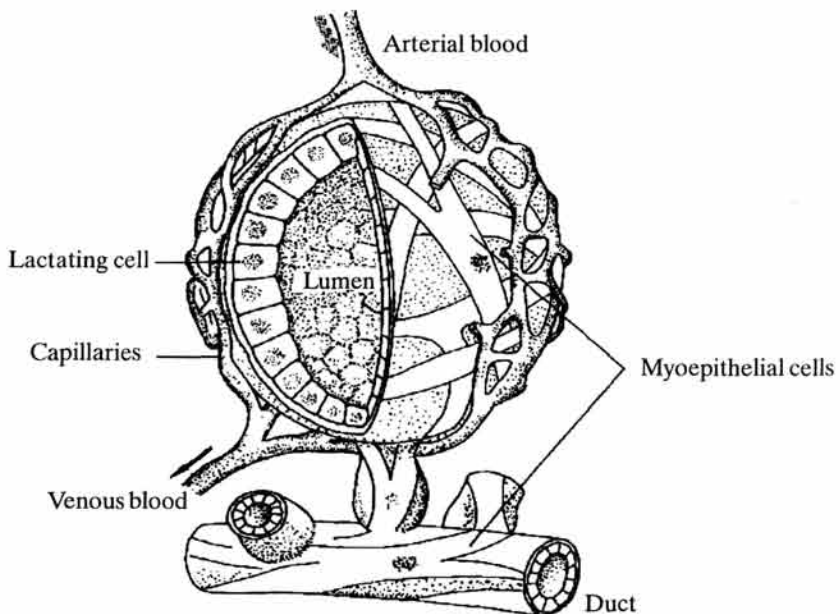


Figure 3: Schematic representation of mammary alveolus (Mephram, 1976)
 Slika 3: Schematski prikaz alveola sise vimena (Mephram 1976)

An alveolus consist of single layer of cells attached to a basement membrane, a vascular system and myoepithelial cells (Figure 3). The alveolar cells are packed close together and are tightly attached to each other. The alveoli are kept together by a thin layer of connective tissue. It contains the nerves and blood vessels. Myoepithelial cells are of ectodermal origin. Myoepithelial cells lie on epithelial side of basement membrane. These cells are surrounding in criss-cross arrangement the alveolus and smaller ducts.

Its structure is flat, branched and contractable and they play an important role in milk ejection. Each alveolus has a short collective duct, which opens to a duct shared by a group of alveoli. (Tanhuanpää,1995). The amount of secretory tissue in the gland is highly correlated with the milk yield. The duct systems of each quarter are independent. The duct system and gland cisterns (Figure 2) carry the milk from secretory tissue to the teats and they serve also as a collecting vessel for part of the milk between milkings (Schmidt, 1971). There are 10 to 12 ducts, which lead into each gland cistern, but sometimes as many as 20 or in the rare cases even more have been found (Schmidt, 1971). The gland cistern is above the teat cistern. The capacity of this cistern varies considerably but is usually from 100 to 400 ml. of milk (Wirz, 1913; Zschokke, 1919). At the end of the teat cistern there is a mucous membrane called Furstenberg's rosette which, by pressing down against the duct opening, blocks the escape of milk from the udder. The end of the udder has one opening called streak canal which usually has length of 8-12 mm, but may range from 5-13 mm and circumference varies from 4-11 mm (Schmidt, 1971). The steak canal is the most important in the prevention of diseases. It keeps dirt and bacteria out of the udder.

Basic aspects of milk components

The nutrients that are needed for the production are supplied from blood. There are two ways in which epithelial cells produce these components. Epithelial cells are present in alveoli and smaller ducts. Most milk components are synthesized in epithelial cells from blood precursors and then released in lumen of the alveolus, while other (for instance minerals, immunoglobulins) move between epithelial cells into the alveolar lumina without alteration by the cells (Schmidt, 1971). Milk secretion rate is partially dependable upon the amount precursors present in the mammary gland. It depends on blood flow through the mammary gland and composition and uptake of components from blood. There are only three components, which are not synthesized from blood (they are only transferred), water, vitamins and minerals. All other components are synthesized from blood precursors.

Component group	Milk component	Blood precursor
Carbohydrate	Lactose	Glucose
Protein	Casein	Amino acids
Protein	β -Lactoglobulin	Amino acids
Protein	α -Lactalbumin	Amino acids
Protein	Milk serum albumin	Blood serum albumin
Protein	Immune globulins	Immune globulins
Fat	Fatty acids	Acetate, β -hydroxybutyrate, blood lipids
Fat	Glycerol	Glucose, glycerol from triglycerides
Water	Water	Water
Ions	Na/K/Cl	Na/K/Cl

a) *Milk lactose*

The major component of most milks is lactose. Lactose is a disaccharide, made up of a glucose and a galactose molecule. It occurs only in the milk and is the only carbohydrate in milk. The glucose transported in the blood and taken up by the secretory cells in udder, come from the liver where it is transformed from propionic acid. Quantitatively sufficient amount of glucose is absorbed by the gland in order to form lactose. The main source of glucose in ruminants is from gluconeogenesis in liver from propionate. Lactose is normally found nowhere in the body but in the mammary gland. The synthesis of lactose is controlled by a two-unit enzyme called lactose synthetase. It consists of two proteins:

1) Galactosyltransferase, which can transfer UDP-galactose to compounds such as N-acetyl glucosamine, but not to glucose.

2) α -lactalbumin

The synthetase step occurs in Golgi Apparatus, while the other steps occur in the cytoplasm.

Schmidt (1971) gives the whole pathway:

- 1) Glucose + ATP¹ \longrightarrow glucose 6-P + ADP²
- 2) Glucose 6-P \longrightarrow glucose 1-P
- 3) Glucose 1-P + UTP³ \longrightarrow UDP-glucose + pyrophosphate
- 4) UDP-glucose \longrightarrow UDP-galactose
- 5) UDP-galactose + glucose \longrightarrow lactose + UDP⁴

¹ ATP - Adenosine Triphosphate

² ADP - Adenosine Diphosphate

³ UTP - Uridine Triphosphate

⁴ UDP - Uridine Diphosphate

Lactose contributes most to osmotic pressure in milk (about 50%) and the rest is contributed by citrate, ions, proteins, etc.

Rook et al. (1965) concluded that a reduction in lactose secretion causes a reduction in water secretion and therefore the milk yield is reduced.

The amount of lactose is decreased during pregnancy due to the fact that progesterone represses the formation of α -lactalbumin.

b) Milk proteins

The concentration of protein in milk varies from 3-4%. The breed and amount of fat determine percentage of milk protein, because there is a close relationship between the amount of fat and protein in milk (the higher the fat content the higher the protein content). Rose et al. (1970) showed that 80% of milk protein is casein (α_s -casein, κ -casein, β -casein and γ -casein). The remaining 20% are whey proteins, which consist mainly of β -lactoglobulin and α -lactalbumin. All these three proteins are synthesized in the udder.

Serum albumin can be present in milk due to the leakage. The immunoglobulins (mainly IgA) is taken up by the endotelial cell by endocytosis from the blood followed by exocytosis into the alveolar lumen.

The protein synthesis consists of two steps: 1) Transcription 2) Translation. Requirements needed for these synthesis are: original DNA⁵ coding sequence (which determine the order of amino acids in the protein chains, mRNA⁶ (messenger RNA), rRNA (ribosomal RNA), tRNA (transfer RNA), amino acids, energy and enzymes. Before the first step (transcription), the separation and duplication of the two strands of DNA occurs by a base-pairing procedure. This pre-step is called replication and has no direct influence on protein synthesis. mRNA is formed from DNA within the nucleus by a basepairing process similar to the one already mentioned in replication process. When mRNA is formed it leaves the nucleus and pass to the cytoplasm, where they bind to ribosomes, and protein production takes place. Second step is translation in which the mRNA is translated towards individual amino acid, transported towards ribosomes by specific tRNA's. This step requires energy from ATP and is specific for coupling amino acid into peptide bonds enzyme. rRNA marks the place of amino acid additions. tRNA transport the correct amino acid to mRNA. At the end the amino acid is connected to a growing chain of amino acids by a peptide bond and tRNA moves toward the cytoplasm in order to pick up another amino acid.

The immunoglobulins play an important role in passing disease resistance to the newborn calf.

⁵ DNA - deoxyribonucleic acid

⁶ RNA - ribonucleic acid

c) Milk fat

Fat is present in milk in a small globules suspended in water. A layer of phospholipids surrounds each globule. The fat content of cow's milk varies from less than 3% to more than 6%, depending on breed, stage of lactation and environmental conditions. It contributes to the energy content of milk. From all major milk components, milk fat is the most varying one among animals within a species. Milk fat is primarily composed of triglycerides (97-98%). It consists of glycerol molecule, which has attached three fatty acids. Fatty acids can be unsaturated and saturated. They differ in the number of carbons in their linear chain length and in the number of double bounds (unsaturated fatty acids). The only difference between ruminant and non-ruminant composition of fatty acids is that ruminants have a relatively high percentage of short chain fatty acids. For fatty acids synthesis starting point is acetyl co-enzyme A synthesis from acetate. The fatty acids of milk triglycerides are synthesized in the mammary gland and in the gland by uptake of chylomicrons and certain blood lipoproteins. Glycerol required for milk triglyceride is partly derived from the hydrolysed blood lipids, partly by synthesis from glucose, and in small measure from free glycerol of the plasma (Mephams, 1976). Milk fat has an important function in carrying fat soluble carotenoids and vitamins A, D, E and K. The lowest fat content is present during peak lactation. At the start of the milking the percentage of milk fat is 1-2%, and at the end 7-9%.

d) Milk water

Water constitutes about 87% of milk. Water is transferred from blood plasma to the milk. Water transport across the apical membrane is governed by osmotic pressure exerted by the secreted solutes (Mephams, 1976). Fat and protein in milk have large molecules and low concentrations and give therefore a low contribution to the small osmotic pressure.

On the other side, lactose and the free ions have a great contribution to the osmotic pressure and have therefore an important role in the transport of water across the apical membrane.

The amount of water in milk is regulated by the amount of lactose synthesized in the mammary gland. It is very important for milk production that cows have free access to the water.

e) Milk ions

The major ions in milk are potassium, sodium and chloride. Jersey breed of cow has 15 mmol Na/l fat free milk, 43 mmol K/l fat free milk and 24 mmol Ca/l fat free milk (Peaker, 1977). These data show that sodium/potassium ration is 1:3. There are two pathways of ion transport: transcellular and paracellular (Peaker, 1977).

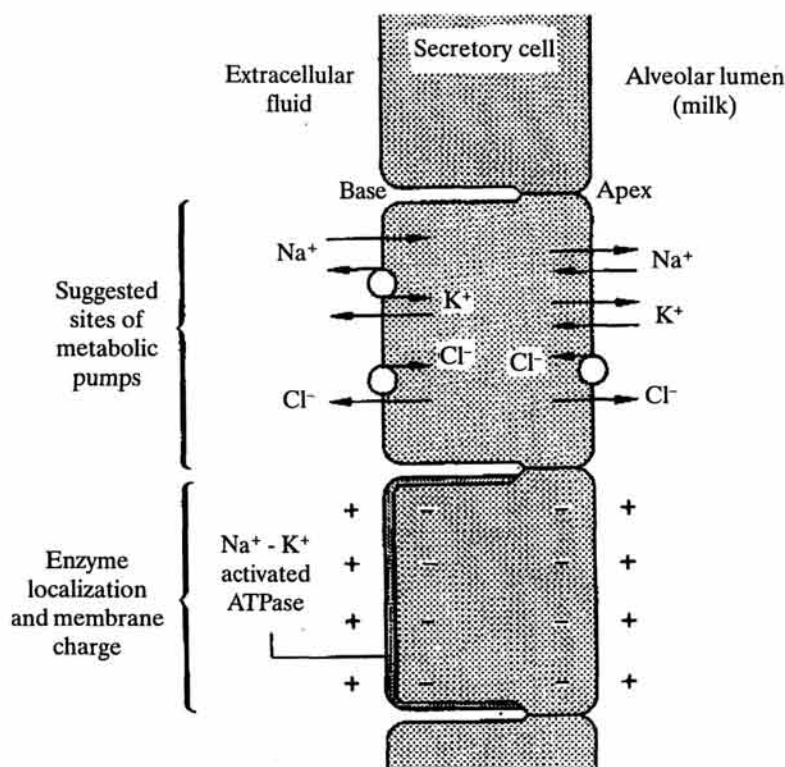


Figure 4: Schematic representation of factors determining ion fluxes from extracellular fluid to milk (Mephram, 1976)

Slika 4: Schematski prikaz čimbenika koji određuju protok iona iz ekstracelularne tekućine u mlijeko (Mephram, 1976)

In transcellular pathway sodium, potassium and chloride have to cross basal and apical membrane (that is across secretory cell).

From Figure 4 it can be seen that in transcellular pathway exist sodium pump which with energy from ATP pump potassium in the cell and sodium out of the cell, therefore there is a high concentration of potassium and low concentration of sodium present in intracellular fluid. There is no sodium pump present in apical membrane, so sodium and potassium diffuse across membrane down their respective concentration gradients. The concentration of sodium and potassium is lower in milk than in intracellular fluid, but their ration remains the same, 1:3 respectively. Chloride ions also diffuse passively down their concentration gradient from intracellular fluid to milk. There are two chloride metabolic pumps present, one at the basal and other at the apical membrane. These metabolic pumps accumulate chloride ions in intracellular fluid, and at the same time they keep a low level of chloride ions in milk.

The milk ejection reflex

Milk ejection reflex is an inborn reflex. It is not controlled consciously. The milking stimuli needed can be suckling of the calf, touch of teats by fingers of milking man, sight of the calf, touch of towel to the teat and the sound of the milking machine. This milking stimuli travel through the spinal cord to the hypothalamus of the brain where centres controlling release of hormones from the anterior pituitary are located. Peptide hormones, such as those of the anterior pituitary, have receptors on mammary secretory cells (Bramley et al., 1992). The hypothalamus stimulates the posterior pituitary gland to discharge oxytocin. This hormone is carried to the myoepithelial cells (which surround the alveoli) by blood. When it reaches the myoepithelial cells, it causes contraction of these cells. With this contraction milk is squeezed to the duct system and the gland cistern. "The lag time from the start of a tactile (manual or mechanical) teat stimulation until the onset of milk ejection lasts usually 1 to 2 min depending of the grade of udder filling" (Mayer et al., 1991; Bruckmaier et al., 1994).

Continual ejection of milk is dependent on the presence of elevated oxytocin concentrations during the entire milking period (Bruckmeier et al., 1998). The kidneys, liver, and mammary gland are mainly involved in removing the oxytocin from the bloodstream (Schmidt, 1971).

The hormone which is involved in mammary growth and maintenance of lactation is prolactin, while when lactation is established growth hormone stimulates milk production. Dairy cows cannot support established milk production without prolactin. Knight et al. (1996) showed that prolactin depletion reduces milk yield in goats by 10% and short term supplementation using recombinant prolactin increases it by about the same amount. By injection of growth hormone and thyroxin in cows, we get a marked stimulation of the milk yield (Mephram, 1976). The hormone which cause cessation of secretion is adrenaline, which appears when a cow is under stress or frightened.

Milking machine

Before the milking occurs, milk is stored on the one hand within the teat, gland cistern and in large milk ducts, while the rest is stored in small ducts and alveoli. The first mentioned milk can be removed, by overcoming the barrier of teat sphincter. The milk stored in small ducts and alveoli is fixed by capillary forces and only can be removed by milk ejection reflex. Therefore, a milking stimulation routine is needed in order to start milk ejection reflex. Velitok (1977) showed that strict "stereotyped" routine provides better milk ejection, reduce proportions of residual milk and increase peak flow milk rate.

Different studies have shown that good pre-milking stimulation causes oxytocin release up to 8 minutes and that is the reason why milking routine has to be strict and milk removal quickly. Good milking routine should (Bramley et al., 1992):

- Provide an environment causing least stress to cows and stockmen,
- Ensure that premilking preparation results in a complete milk ejection before milking is started,
- Ensure that the various associated tasks (foremilking, udder washing, feeding concentrates etc.) are performed in the same order at each milking immediately before the machine is attached,
- Minimises the amount of milk left as stripping at the end of the milking.

In order to obtain efficient milking routine, the following factors must be considered:

- 1) available amount of cisternal milk prior to attachment of milking machine
- 2) timing of milk ejection
- 3) speed of milking

Proper milking in last phase of milking and more frequent milking can reduce the amount of milk in cisterne. Timing of milk ejection should be proper in order to supply enough oxytocin during the milking and that the concentration of oxytocin is maintained at high level. Milking speed can be increased by a higher level of vacuum and a change in pulsation rate and ratio. However, a higher vacuum level could cause eroded teat ends with a negative effect on udder health. Milking vacuum in dairy regions such as Canada and Scandinavia, agreed, based on experience, that teat-end vacuum should not exceed 50 kPa. Milking duration starts with attachment of the cluster to the teats. In less than 60 seconds the flow reaches the peak. Then maximum flow rate is maintained until most of the milk is obtained. In final period the flow is decelerating and it is different for each of the teats. Optimal duration should be around 5 minutes, if cows are milked around 4 minutes they are undermilked (which causes a decrease yield over time) and if they are milked 8 minutes they are overmilked (which causes stress and increase chance of infection). To reduce stripping yield, increased weight of the cluster (between 1.5-3.5 kg) can be applied. The negative effect of increased weight of the cluster is that it can cause more slipping and falling of the cluster. The most important part of the milking machine is liner, which is directly connected with the teat. Usually are used "narrow-bore" liners with a soft mouthpiece lip. The internal diameter of a narrow-bore liner should be at least 1 mm smaller than the average diameter of the teats in the given herd, measured just before milking.

During milking time there are a lot of different microorganisms present, which by entering the udder of the cow could cause a mastitis. This could be prevented by proper care (cleaning of the udder by towel, hot water, ...) in preparation of the milking and also after the milking when teat and stays open for few more hours.

Good teat preparation for milking means that teats are clean and dry. In that period there is a possibility that microorganisms could enter the udder and therefore teats should be dipped. Cows suffer higher udder infection rates if they are milked with high cyclic and irregular vacuum fluctuations then if they

are milked with minimal vacuum fluctuations. It is very hard to say how much milking machines influence mastitis, this subject is more related to the hygiene level of the herd. It could be prevented with proper hygiene and mastitis control.

Recently milking robot was introduced using the standard milking routine. Milking robot gives an opportunity that cows can be milked up to 4 times a day. "Traditionally, cows have been milked two times daily, while milking three times has been shown to increase milk yield by 6 to 28%, depending on parity" (Klei et al., 1997). An additional 5-10% increase in milk yield is obtained with four times milking a day. It also allows the milking frequency for individual cow to be determined. Considering the animal welfare it allows cows to visit the milking robot by their own choice. The milking robot also provides all information about the cow milking performance.

Conclusions

1) From physiological point of view it is very important to have a good developed udder with a lot of secretory tissues, good supporting ligaments, big enough gland cistern and good shape of teats to maintain high milk production. With knowing the pathways of milk components synthesis, we could produce the milk according to our needs.

2) Milking machines are used to take milk out from the udder and they should be designed in a way that keeps the udder healthy. Therefore, milking vacuum should not exceed 500 Kpa, optimal milking duration should be around 5 minutes (for conventional milking), weight of the cluster should be up to 3.5 kg and liners should be chosen according to the average heard teat diameter.

3) Interaction between physiology of lactation and milking machines in order to maintain healthy udder and higher milk yield should be based on good milking machine routine, described by Bramley et al. (1992), regular cow hygiene, regular cow mastitis control, milking pleasant to the cows and optimal presence of three most important hormones (oxytocin, prolactin and growth hormone) for lactation.

FIZIOLOGIJA LAKTACIJE I MEHANIČKA MUŽNJA

Sažetak

Glavni cilj ovog članka je da opiše interakciju između fiziologije laktacije i mehaničke mužnje. To je važno da bi se izbjegli loši utjecaji (npr.: mastitis, broj somatskih stanica, itd.). Dio u kojem je opisana anatomija vimena prikazuje kako je vime potrebno da bi ono bilo zdravo i imalo visok prinos mlijeka. Dio u kojem je opisana mehanička mužnja pokazuje parametre mužnje potrebne za dobru i jednostavnu mužnju. Glavni zaključak o interakciji između fiziologije laktacije i mehaničke mužnje, je da je najvažnije ostvariti dobru proceduru mužnje, regularnu kontrolu higijene krava, regularnu kontrolu na mastitis, za kravu ugodnu mužnju i

prisutnost tri najvažnija hormona tijekom laktacije (oksitocina, prolaktina i hormona rasta).

Ključne riječi: anatomija vimena, komponente mlijeka, sekrecija mlijeka, uređaj za mehaničku mužnju

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Author address - Adresa autora

Mr. sc. Alen Džidić
Zavod za mljekarstvo
Agronomski fakultet
Sveučilišta u Zagrebu

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