Milk Secretion and Quality Standards

Pamela L. Ruegg, DVM, MPVM, Dip. ABVP-Dairy
University of Wisconsin, Madison, USA

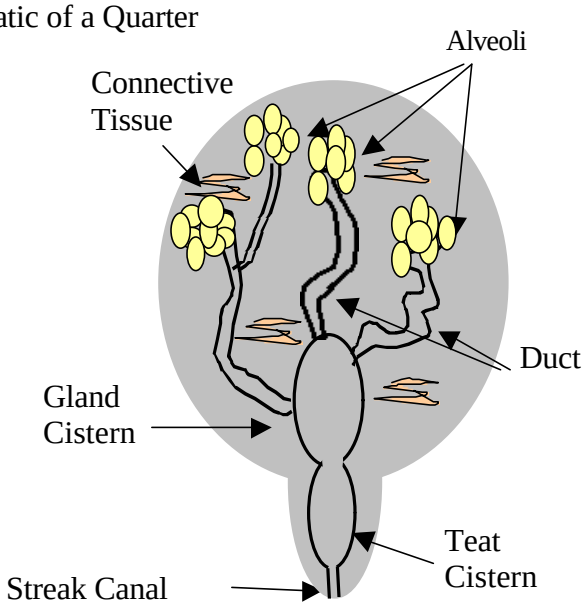
Introduction

The dairy industry is a large and dynamic segment of the agricultural economy of many nations. In 1999, cash receipts from marketing's of milk exceeded $23 billion dollars in the United States. Consumption of dairy products continues to increase throughout the world. The widespread consumption of dairy products and well-publicized recent epidemics of animal disease (such as bovine spongiform encephalopathy "BSE", and foot and mouth disease "FMD") has increased consumer concern about the quality of foods of animal origin. Coincident to these trends, globalization has influenced the definition of "high-quality" milk and consumer expectations are increasingly affecting animal management practices. An understanding of concepts regarding milk secretion and milk quality is necessary to meet evolving consumer expectations.

Udder Anatomy and Milk Secretion

The udder is composed of 4 distinct secretory glands termed "quarters." The "quarter" consists of milk producing secretory tissue, which is referred to as alveoli, a duct system to transport milk away from the alveoli, two storage areas termed "cisterns" and 1 teat. An important component of the teat is the "streak canal," a thick muscular tissue that is lined with antibacterial substances and closes the teat when milk is not being extracted. Each quarter is independent and is separated from the others by thick ligaments (Figure 1). Microorganisms cannot pass directly between the quarters but antibiotics (given either in 1-quarter or systemically) are absorbed and can spread throughout the entire udder.

Figure 1. Schematic of a Quarter



Most of the udder is composed of alveoli and milk is stored in the following proportions: 60% in alveoli, 20% in ducts and 20% in the cisterns. The cells that line the alveoli actually produce the milk; as the alveoli fill with milk, pressure on the epithelial cells increases and milk production slows. Arteries that supply the nutrients for milk production support each alveoli. It is estimated

each ml of milk requires between 500 and 1000 ml of blood to circulate through the udder and 8% of the total blood volume of the dairy cow is present in the udder. Muscle cells surround the alveoli. To extract milk, the muscles around the alveoli must contract to move the milk into the ducts and cisterns. This process is termed "milk letdown". The process of milk letdown is initiated by the environmental and physical stimuli that trigger a series of hormonal events. Positive stimulation signals the pituitary gland in the brain to produce oxytocin. The oxytocin travels to the udder in the bloodstream and causes the myoepithelial cells around the alveoli to contract and move the milk into the duct and cistern system where it can be extracted through the milking process. Negative stimulatory events (such as shouting at the cows, using dogs to chase the cows or striking the cows) stimulate the release of the hormone adrenaline. Adrenaline causes blood vessels to contract and reduces the effect of oxytocin.

Milk composition

Normal milk from high producing Holstein or Friesian dairy cows is composed of water (87%), fat (3.8%), protein (3.4%), sugars (i.e., lactose, 4.5%) and other solids such as minerals (1.3%). Milk also contains a number of minor components including sloughed epithelial cells and white blood cells. High quality milk should be white in appearance, have no objectionable odors and be free of abnormal substances such as pesticides, added water or antibiotic & antiseptic residues.

In most developed dairy countries milk quality is defined by the *somatic cell count (SCC)* and the *bacterial count ("standard plate count" or SPC*) in pre-pasteurized bulk tank milk. Somatic cells are composed of white blood cells (WBC) and occasional sloughed epithelial cells. Most cells found in normal bovine milk are a type of WBC (macrophages) that function as early warning signals when bacteria invade the udder (Table 1).

Table 1. Somatic Cells Found in Bovine Milk[a]

Cell Type	Normal Milk (%)	Subclinical Mastitis
Neutrophil	0 – 11%	>90%
Macrophage	66 – 88%	2 – 10%
Lymphocyte	10 – 27%	
Epithelial cell	0 – 7 %	0 – 7 %

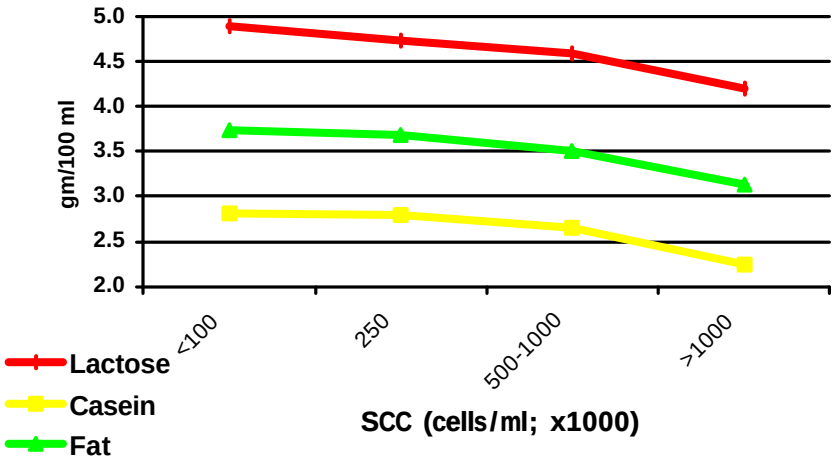
[a]adapted from Lee et al., 1980

The largest factor that influences the SCC of milk is mastitis (Harmon, 2001). The SCC of a cow that is not infected with mastitis is usually less than 200,000 cells/ml and many cows maintain SCC values of less than 100,000 cells/ml. When mastitis causing bacteria invade the udder, the macrophages present in the udder signal the cow's immune system to send neutrophils to the udder to engulf and destroy the bacteria. More than 90% of SCC in infected glands are composed of neutrophils and a SCC of greater than 200,000 cells/ml is almost always caused by mastitis.

Most milk processors prefer to purchase milk with low SCC and in the U.S., many processors offer financial incentives to farmers for high quality milk. High SCC milk is not desirable for processors because it reduces the shelf life of dairy products and diminishes the quality and quantity of milk protein; thereby reducing cheese yields. Even modest increases in individual cow SCC (>100,000/ml) have been shown to reduce cheese yields (Figure 2; Schallibaum, 2001).

Infection with a mastitis pathogen causes injury to secretory cells and reduces the synthesis of lactose, fat and protein. Subclinical and clinical mastitis infections also increase the permeability of cell membranes and allow the leakage of blood components into milk further reducing product yields and quality.

Figure 2. Effect of SCC on Milk Components



The SCC is also important to the dairy producer because of the well-documented relationship between subclinical mastitis (as measured by SCC) and milk yield. A review of 19 papers that studied the relationship concluded that each 2-fold increase in SCC above 50,000 cells/ml resulted in a loss of 0.4 and 0.6 kg of milk per day in primiparous and multiparous cows respectively.[1] It is estimated that total lactational milk yield is reduced by 80 kg for primiparous and 120 kg for multiparous for each 2-fold increase in the geometric mean SCC over 50,000 cells/ml.

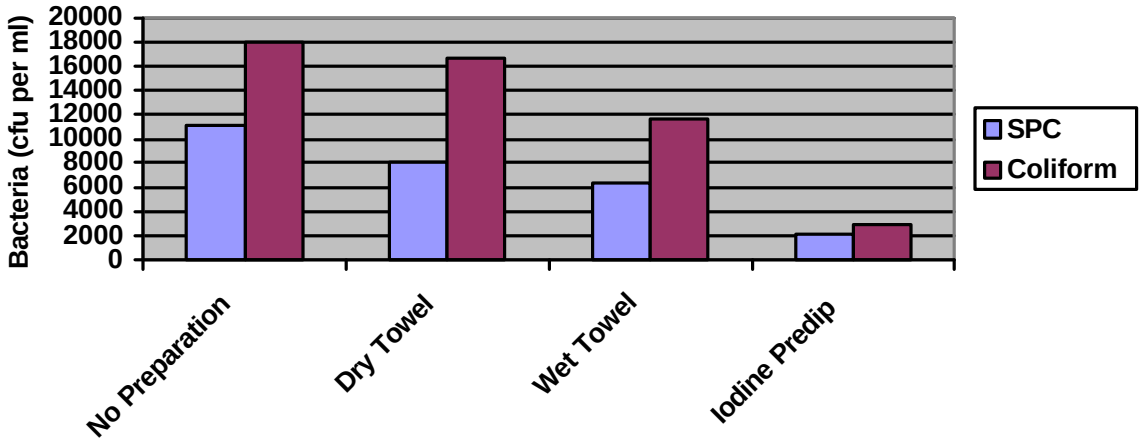
The other major criterion for milk quality is the bacterial count. There are several methods used to evaluate the amount of bacteria present in milk but the most common method is referred to as the standard plate count (SPC) or plate loop count (PLC). This simple test is performed by counting the number of colonies of bacteria that grow after one ml of milk has been incubated on standard media for 48 hours at 32 C. The SPC should be less than 5000 colony forming units (cfu) if cow and equipment sanitation are good and cooling of the milk has been adequately performed. Milk is an excellent growth media for bacteria and a small number of bacteria in milk can rapidly increase to very high numbers especially if milk has not been adequately cooled. Bacteria in milk can originate from either mastitis or from contamination of the milk with environmental pathogens during the milking or milk handling process. The failure to adequately clean milking equipment is often associated with high bacterial counts. High quality milk originates from healthy cows that are free of mastitis. Most mastitis organisms do not continuously shed high numbers of bacteria and therefore are often only associated with high SCC rather than high SPC. Mastitis infections caused by some streptococci spp. can however be associated with increased bacterial counts in milk. Mastitis caused by *Streptococci agalactia* and *Streptococci uberis* has been frequently associated with increased bacterial counts in bulk tank milk.

When bacterial counts increase there are two additional tests that can be performed to help identify the source of milk bacteria (Reinemann, 1997). The lab pasteurized count (LPC) is simply a SPC that is performed on milk that has been pasteurized by heating to 63 C for 30 minutes. This

procedure should kill mastitis causing bacteria that live in the udder and leave organisms that originate in the environment and can survive high temperatures. The LPC should be below 100 to 200 cfu if equipment cleaning and sanitation are adequate. A LPC less than 10 cfu indicates excellent equipment hygiene. A coliform count can be performed to identify bacteria that originate from fecal contamination of milk. Coliform bacteria can contaminate milk through poor udder preparation or unhygienic handling of the milking machines. This test is performed on specialized media (violet red bile agar) and should be less than 100 cfu for milk intended to be pasteurized before consumption and less than 10 cfu if raw milk will be consumed. Coliforms can incubate in residual films left on milk contact surfaces such as milking pipelines or equipment. Coliform counts greater than 1000 suggest incubation and the equipment cleaning process should be investigated.

Proper premilking cow preparation can have a major impact on bacterial counts in milk (Figure 3; Galton et al, 1986).

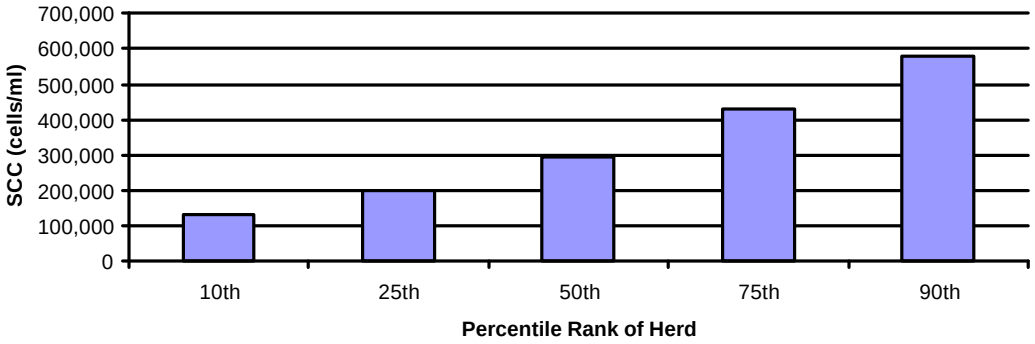
Figure 3. Effect of Udder Preparation on Bacterial Counts



Regulatory Guidelines

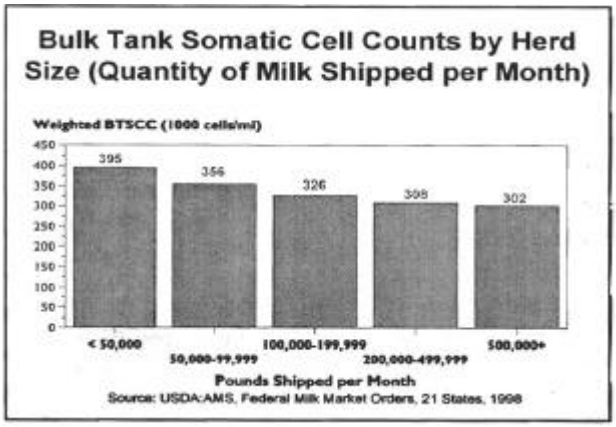
In all developed nations, regulatory officials set allowable maximums for SCC and SPC. In the U.S., states are allowed to determine their own quality standards as long as the standards meet or exceed standards defined by the Pasteurized Milk Ordinance (PMO), a document administered by the Food and Drug Administration. Since 1986, PMO limits for SCC and bacteria have been gradually lowered. The current PMO upper limit for bulk tank SCC is 750,000 cells/ml. Current milk quality standards in Wisconsin include the following requirements: 1) no visible adulteration or objectionable odor, 2) standard plate counts of <100,000 cfu and <300,000 cfu for Grade A and Grade B milk respectively, 3) no drug residues, 4) SCC <750,000, 5) temperature < 7.2^{o} and 10^{o} C for Grade A and Grade B milk respectively, and 6) no pesticide residues. While US standards for SPC are comparable to peer countries, the current US SCC limit is conspicuously higher than Canadian and European standards (500,000 cells/ml for Canada and 400,000 cells/ml for most of the E.U.). In the US, the Centers for Epidemiology and Animal Health surveyed 35% of US milk from 1994 to 1997 and reported a geometric mean value of 297,000 cells/ml. In 1998, 50% of grade A Wisconsin dairy farms produced milk with a SCC of <290,000 cells/ml (Figure 4).

Figure 4. Bulk Tank SCC Percentiles of Grade A Dairy Herds in Wisconsin in 1998



On a national basis, U.S. milk quality is monitored using data from the seven federal milk marketing orders.[7] Nationally, average SCC range from 300,000-400,000 cells/ml. Somatic cell counts are highest in regions with hot humid summers and have a significant relationship with herd size (Figure 5).

Figure 5. United States Department of Agriculture SCC data for 1998



The SCC of milk is not only an indication of milk quality but is also an indicator of the likelihood of the herd experiencing a violative antibiotic residue. Dairy herds with SCC >400,000 cells/ml have been demonstrated to have a higher risk of violative antibiotic residues (Ruegg and Tabone, 2000). In the U.S., every tank truck of milk is tested for the presence of antibiotics prior to the tank being unloaded. If the truck is confirmed positive for the presence of antibiotics, a sample that was collected from each farm is tested to determine which farm contaminated the milk. The entire tanker load of contaminated milk must be dumped and the offending farmer is fined. A farm that repeatedly violates antibiotic residue standards will be prohibited from selling milk. Antibiotic residues are undesirable for public health reasons and because of their potential impact on the manufacturing process (Allison, 1985). U.S. milk regulations prohibit the presence of antibiotics in milk intended for human consumption to protect hypersensitive individuals from exposure to specific antibiotics (primarily penicillin) and to reduce the remote possibility of the emergence of antibiotic resistant organisms in milk. There have been a number of studies looking at reasons for antibiotic residues in milk (Booth and Harding, 1986; McEwen et al, 1991; Oliver et al, 1990; Wilson et al, 1998). Treatment of mastitis is the most common reason for the use of antibiotics on

dairy farms . The use of intramammary antibiotics and mistakes regarding withholding periods of milk are the most frequently cited reasons for antibiotic residues.

Recognizing Milk Quality Problems in Herds

Perception of a mastitis problem varies tremendously between farms. The most frequent reference point for milk quality is the bulk tank somatic cell count (BTSCC). All dairy farms have periodic BTSCC and bacterial count data supplied by their milk purchaser. BTSCC generally reflects the prevalence of subclinical mastitis that a dairy herd is experiencing. BTSCC goals need to be set individually, but the consistent production of milk with BTSCC <250,000 is achievable for many dairy farms. Goals for BTSCC should be set individually based upon current farm status but the ultimate objective should be to consistently ship milk with a ***BTSCC <250,000 cells/ml***.

BTSCC values may verify the existence of a mastitis problem but they do not define the problem on either a herd or individual animal basis. Both BTSCC and simple averages of individual cow SCC values can be misleading. Consider hypothetical Herd "A" with a 10% prevalence of subclinical mastitis (only 1 of 10 cows has SCC of >250,000; Table 2). Due to the high production and high SCC of "Cow 10," the BTSCC for Herd A is 825,000 cells/ml and the arithmetic (non-weighted) average of individual cow SCC is 390,000 cells/ml. In hypothetical Herd "B," 90% of the cows have subclinical mastitis (9 out of 10 cows with SCC > 250,000) but the BTSCC is only 250,000 cells/ml and the simple average of individual cow SCC is 280,000 cells/ml. The underlying mastitis problems for these herds are dramatically different.

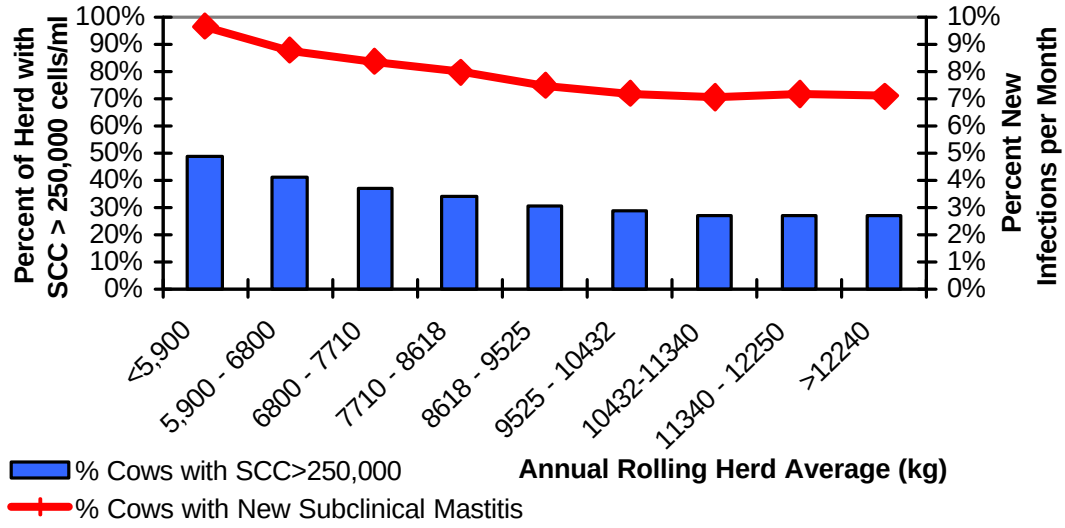
Table 2. SCC Data for 2 Hypothetical Herds

	Hypothetical Herd A				**Hypothetical Herd B**		
Cow	SCC (x1000)	Milk (kgs)	Wt. Avg. (SCCxkgs)	Cow	SCC (x1000)	Milk (kg)	Wt. Avg. (SCCxkgs)
1	100	22.7	2270	**1**	**300**	**22.7**	**6804**
2	100	22.7	2270	**2**	**300**	**22.7**	**6804**
3	100	22.7	2270	**3**	**300**	**22.7**	**6804**
4	100	22.7	2270	**4**	**300**	**22.7**	**6804**
5	100	22.7	2270	**5**	**300**	**22.7**	**6804**
6	100	22.7	2270	**6**	**300**	**22.7**	**6804**
7	100	22.7	2270	**7**	**300**	**22.7**	**6804**
8	100	22.7	2270	**8**	**300**	**22.7**	**6804**
9	100	22.7	2270	**9**	**300**	**22.7**	**6804**
10	**3000**	**68.0**	**204000**	10	100	**68.0**	6800
Estimated BTSCC: 224,430/272 = 825 (x1000)				Estimated BTSCC: 68036/272 = 250 (x1000)			

The prevalence of subclinical mastitis within a herd (the percentage of cows with SCC >250,000) can be determined by obtaining individual cow SCC values or by performing the California Mastitis Test (CMT) on each cow. The prevalence of subclinical mastitis is dependent upon two factors: 1) the new infection rate (the percentage of cows developing new subclinical infections) and 2) the duration of each subclinical infection. Mastitis caused by environmental pathogens (coliforms, and environmental streptococci) is generally of shorter duration than mastitis caused by contagious pathogens (*Staph. aureus*, *Strep. ag* and *Mycoplasma bovis*). The implementation of effective control measures that reduce the rate of new infections can result in rapid reductions in BTSCC when environmental bacteria are the primary pathogens. More gradual improvements in

BTSCC are generally seen when control programs for contagious pathogens are introduced. In the U.S., culling cows that are chronically infected with contagious pathogens is a common strategy for reducing BTSCC. Many mastitis control programs for contagious mastitis are focused too heavily on culling rather than controlling new infections. Common industry goals for subclinical mastitis are: **85% cows with somatic cell counts ≤250,000** and less than ***<5% of cows developing new subclinical mastitis infections each month.***[14] While many herds achieve these goals, many other herds experience considerably more subclinical mastitis than expected. The performance of Wisconsin dairy herds that belong to a Dairy Herd Improvement Association is shown in Figure 6. There were >7000 herds included in the data and no size category had <40 herds contributing. About 40 – 50% of the cows were infected with subclinical mastitis in low producing herds and 29% of cows were infected in high producing herds. Less than 5% of cows were infected with subclinical mastitis in the top 10% these herds.

Figure 6: DHI Herd Summary Data by Production Level for Wisconsin Dairy Herds, June 2000



Recognizing Milk Quality Problems in Cows

For *individual cows*, subclinical mastitis is defined on the basis of their SCC values or CMT scores. Any cow regardless of parity or stage of lactation, with a SCC of ≥250,000 is likely infected with subclinical mastitis. There are several other ways that SCC values for individual cows can be described. The CMT is an indirect measure of SCC and in the absence of individual cow SCC reports, can be used on all cows to determine their infection status. The traditional CMT scoring system is based upon a 5-point scale (negative, trace, 1,2,3). However, all quarters with reactions of trace or more have SCC of at least 300,000 cells/ml and should be considered as infected with subclinical mastitis. One common method of reporting individual cow SCC values is the linear (or log) SCC score.[13] Linear SCC scores were developed because SCC values are not normally distributed, therefore the average SCC value is not a good representation of herd infection status. The approximate relationship between SCC counts, linear somatic cell scores and production loss is demonstrated in Table 3.

Table 3. Relationship between somatic cell score and somatic cell count

Somatic Cell Score	Somatic Cell Count – midpoint (cells/ml)	Approximate Range (cells/ml)	Estimated Milk Lost (kg per Lactation)[a]	
			Lactation 1	Lactation 2+

0	12,500	0 to 17,000	0	0
1	25,000	18,000 to 34,000	0	0
2	50,000	35,000 to 70,000	0	0
3	100,000	71,000 to 140,000	90	180
4	200,000	141,000 to 282,000	180	360
5	400,000	283,000 to 565,000	270	540
6	800,000	566,000 to 1,130,000	360	720
7	1,600,000	1,131,000 to 2,262,000	450	900
8	3,200,000	2,263,000 to 4,525,000	540	1080
9	6,400,000	>4,526,000	630	1260

[a]approximate conversion from pounds

Understanding the relationship between the production of high quality milk and the amount of clinical and subclinical mastitis in the herd is fundamental to the profitability of the dairy business. In the globalized economy consumers are increasingly demanding that food products are produced from healthy, well cared for animals. Meeting consumer expectations will ensure the continuation of a prosperous and stable dairy industry.

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