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Milk pasteurisation and safety: a brief history and update

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Summary

A brief history of the development of milk pasteurisation is presented and updated. Concerns about the margin of safety provided by current pasteurisation standards in terms of milk-borne pathogens such as mycobacteria (in particular *Mycobacterium paratuberculosis*) and other emerging pathogens such as *Listeria monocytogenes* and *Escherichia coli* O157:H7 are discussed. With the exception of the endospores of *Bacillus cereus*, current standards appear to be adequate for public health assurance of milk safety provided good manufacturing practices are followed.

Keywords

Cheese – Milk – Milk-borne pathogens – Mycobacteria – Pasteurisation – Public health.

Introduction

The preservation of foods by heat has probably been practised by man since the discovery of fire. Although sterilisation is an absolute term which usually means the complete destruction of all forms of life, substantial food preservation can be achieved by less than complete sterilisation. Pasteurisation is such a treatment: the name is derived from that of Louis Pasteur, whose discoveries in the 1860s and 1870s demonstrated that heating liquids, especially wines, to fairly low temperatures, such as 60°C, improved the keeping quality during storage. This low-temperature heat treatment destroyed spoilage organisms, but was low enough so as not to destroy the original characteristics of the liquid being treated.

The early history of pasteurisation was reviewed in detail by Westhoff (79) and much of the information below is taken from that paper. The International Dairy Federation has developed a monograph on pasteurised milk which covers all aspects of pasteurisation (2).

Historical background

The custom of preserving milk by heat may be 'as old as the cow and the use of fire'. William Dewes recommended heating milk in the home before feeding to infants (30) some 40 years before Pasteur conducted his experiments. Dewes observed that if the milk was heated to boiling point and cooled quickly, the tendency to spoil was reduced. Also preceding Pasteur was the contribution of Gail Borden who, in 1853, patented a process for heating and condensing milk under vacuum followed by addition of sugar for preservation. However, the element of microbial destruction achieved by the practice of heating milk was not recognised until the work of Pasteur.

The first application of pasteurising heat treatments to milk may have been performed by Soxhlet, who pasteurised bottled milk fed to infants. Gerber and Wieske pasteurised milk in bottles at 65°C for 1 h as early as 1888 (25). The first commercial pasteuriser was made in Germany in 1882; pasteurisation on a commercial scale quickly became common practice in Denmark and Sweden in the mid-1880s. What is believed to be the first commercially-operated milk pasteuriser in the United States of America (USA) was installed in Bloomville, New York in 1893.

In the USA, there were vigorous objections to the wide-spread heat treatment of milk and the debate continued for many years, although the method was recognised by dairy processors as a way of increasing the shelf-life of fluid milk. Early commercial pasteurisation of milk was not generally accepted, but many companies had adopted the process in

secret (58). Several milk-borne diseases, such as typhoid fever, diptheria, scarlet fever, tuberculosis, anthrax and foot and mouth disease, had been recognised before 1900, but information on the destruction of pathogenic micro-organisms in milk was very limited. For example, Smith reported that *Mycobacterium tuberculosis* was killed in 15 min in milk which had been heated to 60°C (68). Russell and Hastings reported that *M. tuberculosis* was killed in a closed commercial pasteuriser in 10 min at 60°C and, based on these data, recommended that milk be heated at 60°C for 20 min to ensure complete destruction (62).

At least 26 reports appeared in the literature between 1883 and 1906 on the thermal death time of *M. tuberculosis* (53). The times and temperatures reported ranged from 50°C to 100°C and 1 min to 6 h. North further pointed out that at least 31 recommendations for time-temperature combinations to pasteurise milk appeared between 1890 and 1927 (53). The first pasteurised milk ordinance was published in 1924 in the November issue of *Public Health Reports*; pasteurisation was defined as a heating process of not less than 142°F (61.1°C) for 30 min in approved equipment (79). The variable reports concerning the thermal death times of *M. tuberculosis* in milk were clarified by the work of North and Park, who confirmed the earlier reports of several investigators and established the recommendation of 61.1°C for 30 min as providing an ample safety margin for destruction of *M. tuberculosis* in milk (54).

Although the 'holder' method (heating milk to 63.5°C for 30 min) was the most widely used, new equipment designs such as plate heat exchangers were underway and were being applied for use as high-temperature short-time (HTST) pasteurisation methods. After some reluctance on the part of public health officials, the first HTST pasteurisation standards were included in the 1933 United States Public Health Service Milk Ordinance and Code. Although pasteurisation standards had now been established, even as late as 1938, milk-borne diseases were still responsible for about 25% of illnesses associated with infected food and contaminated water (75).

The adequacy of HTST pasteurising treatments to ensure destruction of *M. tuberculosis* was difficult to predict from the data provided by North and Park, since they did not report minimum times for temperatures above 65.5°C. Several reports providing additional data on thermal death times of *M. tuberculosis* at higher temperatures and shorter times appeared. For example, Workman studied 17 strains of human and bovine tuberculosis bacteria, 74 strains of *Brucella abortus*, 218 strains of human and 186 strains of bovine streptococci (80). He reported that, in the laboratory, all these organisms were completely destroyed when heated at 160°F (71.1°C) for 15 s. The standard of 161°F (71.7°C) for 15 s was agreed after consideration of HTST treatment on the creaming ability of milk, practical experience and numerous other investigations (79).

Research following the description of *Coxiella burnetii*, the rickettsia responsible for Q fever, detailed the presence of this organism in raw milk. Early investigations of Q fever in California demonstrated that the organism was more heat-resistant than *M. tuberculosis*, and could be isolated from pasteurised milk processed according to minimum standards (34). Later work by Enright *et al.* showed that if large numbers of the Q fever organism were present in raw milk, some would survive pasteurisation at 143°F (61.7°C) for 30 min (16). This study led to the Public Health Service recommendation to increase pasteurisation standards to 145°F (62.8°C) for 30 min. At that time, the suggestion was also made that an additional 5°F (3°C) be added when products containing more fat than found in fluid whole milk, or containing added sugar, were to be pasteurised. Pasteurisation standards today are based on the destruction of *C. burnetii*.

When the thermal death time curve of *M. tuberculosis* was updated (38), results indicated that the z-values (the z-value is the temperature required for the thermal destruction curve to traverse one log cycle) of three strains of this organism ranged from 4.8°C (8.6°F) to 5.2°C (9.4°F): these values were considerably lower than the z-value of about 12°F (6.6°C) calculated from previously existing data. Kells and Lear concluded that the pasteurisation standard provides a safety margin of about 28.5 min at 61.7°C and about 14 s at 71.7°C (38).

Simultaneously, use of higher temperatures for pasteurisation and sterilisation were being developed. Conventional HTST systems (indirect heating systems), direct heating systems in the form of direct steam injection into the milk, or steam infusion where milk is injected into an atmosphere of steam, were all being used at temperatures above the minimum time-temperature conditions already established to reduce bacterial loads further. The time-temperature combination chosen would determine whether the process was an ultra-high temperature (UHT) pasteurisation process or a UHT sterilisation process. Milk pasteurised under UHT pasteurisation conditions must be refrigerated after heat treatment. UHT sterilisation processing destroys not only pathogenic bacteria but also bacterial spores, the most heat-resistant forms of bacteria. As a result, milk products sterilised in this manner and packaged under aseptic conditions, may be stored at ambient temperatures for 6 months or more. UHT sterilised milk processing is in common use today, especially in Europe. A discussion of UHT sterilisation is beyond the scope of this paper; further details may be obtained from Burton (6) and Bulletin No. 133 published by the International Dairy Federation (1).

Today, in the USA, 'pasteurised', when used in describing a dairy product, means that every particle of the product has been heated in properly operated equipment to one of the temperatures specified in Table I, and has been held

Table I
Current legal pasteurisation standards (21, 74)

Method/product	Time	Temperature
Batch or vat ('holder') pasteurisation		
Milk	30 min	145°F (62.8°C)
Cream	30 min	150°F (65.6°C)
Frozen dessert mix	30 min	155°F (68.3°C)
High-temperature short-time (HTST) pasteurisation		
Milk	15 s	161°F (71.7°C)
Cream	15 s	166°F (74.4°C)
Frozen dessert mix	25 s	175°F (79.4°C)
Condensed milk (to be repasteurised)	15 s	166°F (74.4°C)
Ultra-high temperature (UHT) pasteurisation		
All products	1.0 s	191°F (88.3°C)
	0.5 s	194°F (90.0°C)
	0.1 s	201°F (93.0°C)
	0.05 s	204°F (95.6°C)
	0.01 s	212°F (100°C)
Ultra-pasteurisation		
All products	2 s	280°F (137.8°C)

continuously at or above the temperature for the specified time, or at some other time/temperature relationship which has been shown to be equivalent for microbial destruction (21, 74).

'Ultra-pasteurised', when used to describe a dairy product, means that the product has been thermally processed at or above 280°F (137.8°C) for at least 2 s, either before or after packaging, so as to provide a product which has an extended shelf-life under refrigerated conditions (21, 74).

The International Dairy Federation notes that 'pasteurisation is intended to avoid public health hazards in the sense that, although it may not destroy all pathogenic micro-organisms which may be present, it reduces the number of harmful micro-organisms to a level at which they do not constitute a significant health hazard' (4, 5).

Determination of the adequacy of pasteurisation is vital to ensure the safety of pasteurised milk and milk products. Since an enumeration of the total bacterial load and individual tests for detection of pathogenic bacteria in pasteurised milk require time-consuming procedures, the need for a rapid test method was identified in the early days of pasteurisation development. Milk contains at least 20 enzymes which have been shown to be native constituents; one of these, alkaline phosphatase, is believed to have a thermal resistance (z = 8.7°F) (4.8°C) greater than that of the most heat-resistant of the non-spore-forming pathogens commonly found in milk. This property provided the basis for a negative test for alkaline phosphatase to indicate proper pasteurisation of skimmed or whole milks, and official methods for this test are well-established (47). Recontamination of pasteurised milk is a separate issue and varies from country to country, depending on the hygienic practice. Consequently, very different methods may be required and a catalogue of tests for detection of inadequate pasteurisation or recontamination is available (4, 20); a detailed discussion of these methods is beyond the scope of this paper.

Current issues

Despite the improvement in the quality of the milk supply in the USA through research, education, standards development, evaluation and certification activities, there are still occasional outbreaks of milk-borne diseases, even though these comprise less than 1% of the reported disease outbreaks associated with contaminated food and water (75). This only emphasises the need for continued vigilance at every stage of milk utilisation, from production to distribution and consumption.

Mycobacterium tuberculosis complex

Pulmonary tuberculosis has been one of the great scourges of humankind; numerous studies have demonstrated the presence of mycobacteria in milk (7, 33, 49, 55).

Classification of acid-fast bacilli isolated from raw milk has identified *M. tuberculosis*, *M. bovis*, *M. smegmatis*, *M. avium* and *M. fortuitum*, as well as other acid-fast bacilli such as *Nocardia*. The *M. tuberculosis* complex also includes *M. africanum* and *M. microti* (11). Consumption of raw milk contaminated with pathogenic mycobacteria has been associated with human disease; humans are extremely susceptible to disease from *M. bovis* (24, 56). Although other avenues of environmental exposure, such as contaminated soil or water supplies, may account for some cases of human disease, transmission of mycobacteria from raw milk appears to be the most likely route of exposure (26, 69).

The presence of mycobacteria in the milk of cows subclinically infected with tuberculosis was once a major public health issue (77). Reports have indicated that children under 15 years of age are most susceptible to infection, with resultant lesions in cervical and abdominal lymph nodes (76). Major international bovine tuberculosis eradication campaigns resulted in virtual elimination of *M. bovis* from cattle herds in the USA; the incidence is presently estimated at 0.003% (17). The adoption of milk pasteurisation standards aided in the eradication process. Therefore, the discovery that tuberculosis has not been eradicated but is reappearing in the USA as outbreaks of multiple drug-resistant *M. tuberculosis* has been particularly unexpected (10). Seventy-three patients with microbiologically documented *M. bovis* infections have been identified over a recent twelve-year period (1980-1991); 80% of the patients were of Hispanic origin (11). The immigration of high risk populations and human

immunodeficiency virus infection have apparently reversed the annual 5% decline in the incidence of tuberculosis in the USA (11). Deterrents to tuberculosis eradication have been identified as being infected cervid herds (elk, especially, and bison) in the USA and Canada (46, 52). In addition, a recent resurgence of bovine tuberculosis in the livestock industry of Mexico and the ongoing importation of steers from Mexico into the USA has prompted a review of proper methods for management of colostrum and milk from infected cows (18). *M. bovis* remains endemic in beef and dairy cattle herds in Mexico (11, 17). This resurgence of a 'forgotten' disease re-emphasises the importance of careful handling practices for milk and milk products.

Other mycobacterial agents isolated from raw milk which have been classified as known human pathogens are *M. smegmatis, M. avium* and *M. intracellulare* (33). Although the environment serves as the major source of human exposure to these pathogens, animals may also serve as a reservoir for human infection (44). Rapid-growing acid-fast bacteria such as *M. smegmatis* have been isolated from cows with mastitis (60). Similar to other forms of mastitis, mycobacterial intramammary infections are characterised by abnormal mammary secretions, oedema and localised inflammation of affected quarters. There has been speculation that mycobacterial intramammary infections occur secondary to severe clinical mastitis, and that these mycobacteria may be more accurately described as opportunistic pathogens (64). Reports have associated this type of mastitis with the introduction of mycobacteria into the teat canal as a contaminant during antibiotic therapy for other mastitic organisms compounded by poor sanitation (40).

Mycobacterium paratuberculosis, the mycobacterium responsible for paratuberculosis (Johne's disease) in ruminants, has been implicated as the pathogen which causes Crohn's disease in humans. Of the common clinical signs shared by paratuberculosis and Crohn's disease, the most significant is the localised intestinal inflammation found in both disorders. The consumption of milk or dairy products has been cited as one possible source of human exposure to *M. paratuberculosis* since the presence of paratuberculosis DNA has been documented in cow milk obtained from retail markets in Great Britain (45). Cows with clinical paratuberculosis have been found to shed *M. paratuberculosis* in milk, albeit in low numbers, and the organism has been isolated from mammary tissue and regional lymph nodes (72). However, there is no evidence to date to indicate that viable *M. paratuberculosis* can be cultured from milk after pasteurisation.

The presence of mycobacterial pathogens in raw milk suggests a potential public health hazard. The use of raw milk in the production of cheese and other dairy products has further exacerbated the problem as mycobacteria have been cultured from aged cheeses (39).

There is a wide belief today that pasteurisation of raw milk adequately kills any contaminating mycobacteria which may be present, making the milk safe for human consumption. Further studies have demonstrated that after pasteurisation of raw milk contaminated with *M. tuberculosis*, no growth could be detected on selective growth medium (81). Strains of *M. avium* and *M. fortuitum* were isolated from homogenised, flash-pasteurised milk samples, although there was speculation that contamination during the processing procedure may have been responsible (8).

Other studies have shown that pasteurisation of raw milk either by the 'holder' method (63.5°C, 30 min) or the high-temperature, short-time method (HTST: 71.7°C, 15 s) was effective in destroying these strains of mycobacteria (13, 31). Laboratory simulation of either method is difficult, and experimental methods vary widely among laboratories. Examples of this include studies conducted using a test-tube model to simulate the holding vessel during heat inactivation: with this model, treatment of raw milk experimentally inoculated with various strains of mycobacteria at 63.5°C for 30 min completely inactivated *M. bovis* and *M. fortuitum*, but some survival of *M. avium, M. intracellulare* and *M. kansasii* was evident (28). Similarly, *M. paratuberculosis* survived in milk when held at either 63.5°C for 30 min or 72°C for 15 s using the test-tube model (9). Improvement of the laboratory-scale pasteuriser system to simulate an HTST heat-exchanger as used in commercial systems decreased the numbers of viable *M. paratuberculosis* cultured from milk compared to the test-tube model, yet small numbers still survived (≤1%) (27).

More recently, studies were conducted to evaluate heat inactivation of *M. paratuberculosis* in raw milk by the holder test-tube method and a method using a flow-through laboratory-scale pasteuriser system designed by a commercial manufacturer (71). Results from these studies show that *M. paratuberculosis* survived heat treatment at 65°C for 30 min using the test-tube model; however, treatment of milk at 72°C for 15 s in the flow-through pasteuriser unit effectively killed all bacteria present. These studies demonstrate that the vigorous mixing induced by turbulent flow of the milk during pasteurisation, as occurs in commercial operations, is essential to ensure a uniform temperature for complete destruction of contaminating *M. paratuberculosis*.

Contamination of raw milk with mycobacteria is seemingly unavoidable, even under the most sanitary conditions, since many strains are ubiquitous in the environment. Heat treatment of raw milk using current commercial pasteurisation protocols appears to ensure adequate destruction of contaminating mycobacteria which may be present. Therefore, transmission of viable mycobacteria to humans through pasteurised dairy products seems unlikely: pasteurisation minimises the threat of mycobacteria as causative factors in human disease.

Other pathogens in milk products

Recent experimental data show that the recommended HTST time/temperature combination of 71.7°C/15 s ensures virtually complete elimination of pathogenic bacteria (36, 71). A compilation of some D-values (the D-value is defined as the time in minutes needed to kill 90% of the bacteria present at a specific temperature) of pasteurisation and sub-pasteurisation temperatures for selected bacteria which may be found in raw milk is shown in Table II. Depending on the country of origin, species, climate and sanitary conditions, raw milk and dairy products can contain one or more of the pathogens listed. These data illustrate the pathogen destruction potential of the temperatures used. All of these pathogens are ubiquitous in nature and are easily isolated from the environment (farm and unsanitary processing plants). *Bacillus cereus* is the only pathogen listed which forms an endospore. The growth ranges of the listed pathogens are described in Table III. With the development of more drug-resistant micro-organisms, there is continued concern about the efficacy of the milk processing standards in current practice world-wide.

Table II
A compilation of D-values for selected pathogenic bacteria found in milk (adapted from 70)

Organism	Temperature (°C)	Maximum D-value (minutes)
Bacillus cereus	100	3-27
Brucella abortus	71	0.17 [a]
Campylobacter jejuni	55	1.0
Coxiella burnetii [b]	71	0.25
Escherichia coli 0157:H7	64.5	0.27
Listeria monocytogenes	71.5	0.07
Mycobacterium tuberculosis	65.6	0.03 [a]
Staphylococcus aureus	71.7	0.29
Salmonella Senftenberg 775W	62.8	0.02
Yersinia enterocolitica	–	0.96

a) D-value estimated from the reported survival time; these results need careful interpretation
b) Enright (15)

A brief description of each pathogen in relation to the dairy industry is given by Flowers *et al.* (20) and each pathogen is reviewed in the Foodborne Disease Handbook (12, 19, 23, 43, 51, 63). Most of the information below is taken from the literature cited.

Salmonella

El-Gazzar and Marth have discussed the continued public health concerns in the USA and world-wide about salmonellosis due to recent outbreaks and because of continued isolation from the dairy plant environment (14). Beef and dairy cattle can carry *Salmonella*. Outbreaks of bovine salmonellosis can result from raw milk contaminated with *Salmonella* from either faeces or asymptomatic mastitis. *Salmonella* does not survive pasteurisation, but the largest outbreak of salmonellosis in USA history occurred in 1985

Table III
Growth range of recognised dairy product pathogens (adapted from 36)

Organism	Growth range			
	Temperature (°C)		pH	
	Minimum	Maximum	Minimum	Maximum
Salmonella	6.5	57	4.5-4.7	9-11
Listeria monocytogenes	1	45	4.8	9.6
Bacillus cereus [a]	6	37	4.3	9.3
Brucella abortus	NA	NA	< 4.5	NA
Brucella sp.	6	42	> 4.5	NA
Campylobacter jejuni	25	43	5.5	8.0
Coxiella burnetii	33	37	4.0-4.5	NA
Yersinia enterocolitica	1	44	4.4	9.0
Escherichia coli	2.5	45	4.6 [b]	9.5
Staphylococcus aureus	7	48	4.0	9.8

a) adapted from Johnson (37)
b) recently reported acid-resistant strains
NA: not available

with 'pasteurised' milk containing only 2% milk fat. Investigation into the cause of this outbreak indicated no irregularity in processing but *Salmonella* was isolated from various points within the processing plant, especially from valves linking the raw and pasteurised milk tanks (20).

Salmonellosis has been associated with cheese: there have been reports that the organism can grow and survive in cheese during more than 60 days of refrigerated storage provided that the pH does not fall below the minimum for growth (Table III). The four syndromes of salmonellosis have been reviewed by Ziprin (82). The gastrointestinal illness which develops from ingestion of the organism can be treated successfully with antibiotics, but there is a segment of the population which will develop serious complications and may even die, if infected.

Listeria monocytogenes

The disease caused by *Listeria monocytogenes* was identified more than 100 years ago, but has only recently become a major foodborne pathogen. Infected bovines can excrete the organism into milk, blood and faeces, and the cow usually aborts her calf (12). Consumption of raw milk containing *Listeria* may result in human listeriosis. The outbreaks of illness and fatalities associated with this organism have led to increased surveillance of all milk products by the United States Food and Drug Administration. Control of *L. monocytogenes* is important to the dairy industry because of the ability of the pathogen to grow at refrigeration temperatures (Table III); the behaviour of this pathogen in dairy products has been reviewed elsewhere (29, 57). *Listeria* does not survive pasteurisation (Table II). The reported cases of listeriosis associated with dairy products were determined to be due to post-pasteurisation contamination. Several product recalls due to *Listeria* contamination have involved

ice cream or other frozen desserts (61), but pasteurisation guidelines are adequate to ensure inactivation (32). *Listeria* does not grow during the ripening of hard or semi-hard cheeses, but is reported to grow on the surfaces of soft cheeses (70), so care must be taken to avoid contamination of the ripening room.

Bacillus cereus

Bacillus cereus forms endospores which are heat-resistant to pasteurisation (Table II) but the vegetative cells are rapidly killed at 65°C (65). The spores are associated with mastitis and can easily be isolated from the environment. Johnson reported a list of the dairy products from which *B. cereus* was isolated: products ranged from raw to UHT-processed milk (37). The spores themselves are not the causative agent in illness but release enterotoxins upon germination. Two distinct symptoms of gastroenteritis due to the toxins are reported: vomiting and diarrhoea (63).

In addition to causing illness, *B. cereus* is a major spoilage organism for the dairy industry; details may be found in bulletins of the International Dairy Federation devoted to this organism (3, 78). An example of spoilage in fluid products is the defect known as 'bitty cream'. The spores are also contaminants in dry dairy products such as non-fat dry milk, which may be incorporated as food ingredients; the number of spores present is derived from the number present in the raw milk (3). The spore content of powders used for the manufacture of infant formula should not exceed 100/g (3).

Campylobacter jejuni

The National Advisory Committee on Microbiological Criteria for Foods (48) has published a review of all aspects of *Campylobacter jejuni* and *C. coli* and the reader is referred to this reference for details. The Centers for Disease Control now consider *C. jejuni* to be the most frequent cause of diarrhoeal illnesses in the USA, with an infective dose of 2 to 3 cells/ml (20). Complications associated with infections of *C. jejuni* range from abdominal pain so severe as to mimic appendicitis, to reactive arthritis, Reiter's syndrome or the Guillain-Barré syndrome (66, 67). In the bovine, the udder and intestines are the potential reservoirs for this zoonosis. Raw milk and poultry are known vehicles for outbreaks of campylobacteriosis (23). This organism does not survive pasteurisation (Table II) and proper refrigerated storage prevents growth in contaminated milk (Table III). As a result of sensitivity to sodium chloride concentrations above 1%, the organism also does not survive the acid development and salting processes in cheesemaking. *C. jejuni* is not considered a problem in properly processed dairy products.

Yersinia enterocolitica

Yersinia enterocolitica is found in the gastrointestinal tracts of warm-blooded animals, including dairy cattle. Only the pathogenic strains will cause gastroenteritis in humans; details are provided by Feng and Weagant (19).

Raw milk has been demonstrated to carry *Yersinia*: surveys have shown that the incidence varies from 10% to 81% positive samples. There has been concern that pasteurisation would not destroy the organism, but all indications show that pasteurisation is effective (Table II). Post-pasteurisation contamination is responsible for isolation of the pathogen from finished dairy products. *Yersinia* has been reported to survive in hard cheese for more than 56 days of storage (70). As a result of acid sensitivity, *Yersinia* will not survive at pH 4.4 or below (70).

Escherichia coli

Any strain of *Escherichia coli* which causes diarrhoeal disease in humans is considered to be enteropathogenic (20). *E. coli* is readily isolated from the intestinal tract of warm blooded animals, including dairy cattle (51). Raw milk is contaminated through contact with faecal material; *E. coli* may also be isolated from the milk of mastitic animals. *E. coli* does not survive pasteurisation (Table II); the presence of coliforms in pasteurised milk is commonly used by dairy plants as an indicator of post-pasteurisation contamination. Of concern are the soft and semisoft surface ripened cheeses which have been implicated in numerous outbreaks. If raw milk is used during cheesemaking, *E. coli* counts increase during processing. The organism continues to grow during ripening but may decrease after seven days of storage (70).

Of greater concern is the survival of enterohaemorrhagic *E. coli* O157:H7 in processed dairy products. The first linkage of this organism to raw milk was in 1986 when two patients developed haemolytic uremic syndrome after drinking raw milk (42). A recent study (59) describes the results of a standard Cheddar cheese preparation process from 'holder' pasteurised cheese milk inoculated with one colony-forming unit (CFU) of *E. coli* per ml of pasteurised cheese milk. Results showed that some *E. coli* O157:H7 cells could survive the 60 days storage period at ≥2°C required by the United States Food and Drug Administration for cheese made from raw milk. Even though the low number of outbreaks suggests that pathogens in cheese are not a major problem, the current ripening requirement will not assure consumers of a safe product if the cheese is made from raw milk and a pathogen such as *E. coli* O157:H7 is present at the beginning of the ripening process (41).

Staphylococcus aureus

The aetiology of *Staphylococcus aureus* has been reviewed (43). This bacterium produces a heat-stable enterotoxin which survives pasteurisation (although the organism does not) and, when ingested, causes nausea, vomiting and diarrhoea. Infected dairy cattle can shed enterotoxigenic strains of *S. aureus* in milk; however, outbreaks are rarely caused by drinking raw milk. *S. aureus* is a poor competitor and is readily outgrown by lactic acid-producing micro-organisms, so growth is limited in raw milk; if the milk is not refrigerated, the organism can grow and produce enterotoxin; there has been one reported outbreak of this

nature. Although lactic acid does inhibit growth, hydrogen peroxide formation is also important because only those strains producing high levels of peroxide are effective inhibitors (35). The greatest problem with *S. aureus* contamination occurs during cheesemaking, because most of the organisms are trapped in the curd (73). Prior to the 1970s, cheese made with milk containing *S. aureus* with a count of 10^{7-8}/ml was of concern (20). If the milk was not handled properly, the organism would produce enterotoxin which was not destroyed by pasteurisation. *S. aureus* concentration is reported to increase during the first 24 h of cheese storage but not thereafter. However, numbers of *S. aureus* could be underestimated due to die-off during the ripening period, and analysis for the enterotoxin is recommended. An alternative analysis determines the presence of a thermostable nuclease (20). Current United States Standards of Identity (22) permit treatment of the cheese milk with hydrogen peroxide and catalase specifically to reduce *S. aureus* numbers during manufacture of cheeses such as Cheddar and Colby.

Enterobacter sakazakii

Enterobacter sakazakii has been implicated in a severe form of neonatal meningitis, but information is scarce on the pathogenicity of this organism. Studies have not yet identified a reservoir and mode of transmission, but dried infant formula has been implicated in sporadic cases of *E. sakazakii* meningitis (50). There are no data in the literature concerning the growth potential of this organism in infant formula at various temperatures; unpublished data by Nazarowec-White at Health Canada showed generation times to be 40 min at 23°C and 4.98 h at 10°C. The strains tested did not grow at 4°C and appeared to die off during storage (50). Further research is needed to determine the incidence and survival of this putative foodborne pathogen in dairy foods.

Conclusions

Since pathogenic micro-organisms are readily isolated from raw milk, many State health departments, the United States Food and Drug Administration and the International Dairy Federation strongly recommend that unpasteurised milk should not be drunk or used in the manufacture of any dairy product and specifically not in cheese manufacture. Disease outbreaks from raw milk are usually associated with children visiting a dairy farm and drinking the raw milk. Disease outbreaks associated with cheese made from unpasteurised milk indicate that the 60 days of ripening required before distribution may not be sufficient to completely eliminate pathogens such as mycobacteria (39), *Salmonella*, *Listeria* and *E. coli* O157:H7. Pasteurised milk is usually considered pathogen-free with the exception of the spores of *Bacillus cereus*, if present in large numbers. When a milk-borne disease outbreak occurs, the cause is usually either post-pasteurisation contamination or improper processing. The dairy industry and public health regulators must remain vigilant to ensure that all measures are taken to prevent the entry and multiplication of pathogenic micro-organisms during the handling and processing of milk and milk products to prevent any pathogen-associated illness.

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Pasteurisation du lait et hygiène : bref rappel historique et mise à jour des connaissances

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Résumé

Les auteurs retracent brièvement l'histoire de la pasteurisation du lait et présentent une mise à jour des connaissances dans ce domaine. Les problèmes relatifs à la marge de sécurité fournie par les normes actuelles de pasteurisation sur les niveaux admissibles d'agents pathogènes dans le lait, telles les mycobactéries, en particulier *Mycobacterium paratuberculosis* et d'autres agents pathogènes émergeants tels *Listeria monocytogenes* et *Escherichia coli* O157:H7 sont présentés. À l'exception du cas des endospores de *Bacillus cereus*, les normes actuelles semblent suffisantes pour garantir l'innocuité du lait, sous réserve du respect de bonnes pratiques de fabrication.

Mots-clés

Agents pathogènes présents dans le lait – Fromage – Lait – Mycobactéries – Pasteurisation – Santé publique.

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Pasteurización e inocuidad de la leche: breve repaso histórico y situación actual

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Resumen

Los autores trazan una breve panorámica histórica del desarrollo de la pasteurización de la leche y exponen la situación actual en este campo. Abordan cuestiones ligadas al margen de seguridad que las normas de pasteurización vigentes ofrecen con respecto a la presencia de patógenos en la leche, tales como las micobacterias, especialmente *Mycobacterium paratuberculosis*, u otros patógenos de reciente aparición, como *Listeria monocytogenes* o *Escherichia coli* O157:H7. Con la salvedad de las endoesporas de *Bacillus cereus*, las normas actuales parecen adecuadas para asegurar la inocuidad de la leche en términos de salud pública, siempre y cuando se respeten las buenas prácticas de fabricación.

Palabras clave

Leche – Micobacterias – Pasteurización – Patógenos presentes en la leche – Queso – Salud pública.

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