Does raw milk kill pathogens?
A visual analysis of the research on competitive exclusion

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August 2009

"It is imperative that the citizens of our nation, not just California, have an informed choice in foods."
California raw milk dairyman, May 2004

"Drinking raw milk is like playing Russian roulette with your health."
John Sheehan, Food and Drug Administration

"Raw milk is great. I used to get it straight from a friend's small dairy. You just have to know that every five or six years, you are going to puke your guts out. Besides that, it's great."
Amanda Rose's friend Mike, July 14, 2009, Seattle
Editor's note: Your results may vary.

This short paper was written with no funding from the FDA, CDC, USDA, "big dairy," or "big ag." No cows or goats were harmed in the writing of this paper.

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ISBN 978-1-934712-01-6

This paper contains many details concerning raw milk. Although great care was taken to ensure the accuracy of the text, all individuals have unique medical needs and should seek advice from a qualified health professional. The paper is a resource on raw milk, not a substitute for medical treatment. The author and the publisher are not engaged in medical treatment and are not providing medical advice to individual readers. The author and the publisher shall not be held liable for any harm or loss purported to arise, directly or indirectly, from any information in the paper.

Purple Oak Press
P.O. Box 37
California Hot Springs, CA 93207

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Foreword

There is a great deal of incomplete and inaccurate information on the Internet about raw milk. If you ask the FDA "Does raw milk kill pathogens?," it may direct you to its Raw Milk Questions and Answers, where it responds, "No, it does not."

On the other hand, you have probably heard that if pathogenic bacteria are added to raw milk, raw milk kills pathogens within twenty-four hours. This is a process of "competitive exclusion" whereby a component in the raw milk itself, such as the lactoperoxidase enzyme, kills disease-causing micro-organisms, making the raw milk safe.

Both of those views of the raw milk world are simple and easy to understand, but like most things in life, the answer is far more complicated.

I present key findings on raw milk's pathogen-killing ability here in this short report. I cite the body of research referred to by both raw milk advocates and opponents. They find the research useful enough to quote and, as a result, I find it useful to examine in detail. I am not a microbiologist. In fact, my Ph.D. is in political science. I am far better schooled in explaining to you how raw milk consumers may vote in the next presidential election than I am in explaining the degree to which raw milk kills pathogens. I do recognize my own limitations and had an infectious disease expert read this report for accuracy. That expert would urge you not to consume raw milk because it can contain pathogens. The expert, nonetheless, felt it was important that raw milk consumers have full information about their choice to consume raw milk.

We are all at different stages in life with different levels of risk we can shoulder. For my part, I see raw milk as a healthy option except, of course, when it's not. It does have a small chance of harboring a pathogen that could make you very sick (or worse). If you are a raw milk consumer or considering drinking raw milk, you have the right to know that. In my opinion, you also have the right to drink it anyway.

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Introduction

Most milk available in the grocery store is pasteurized. In large processing plants, the milk is channeled through stainless steel tubes and heated to about 160° F for 15-20 seconds and then immediately cooled. The heat exposure kills off disease-causing organisms, but raw milk advocates argue that the heat treatment also kills vitamins and beneficial bacteria. Advocates argue further that the beneficial components in milk themselves work to keep the raw milk safe in a process called "competitive exclusion." Beneficial bacteria or enzymes in the milk itself protect the milk against contamination by killing pathogens.

If you have ever consumed raw milk, you may agree that the sheer goodness of its flavor surely must kill pathogens. But some of the best-tasting foods on Earth have some risk of harboring pathogens or parasites. It is up to consumers to decide if the risk of illness is worth the pleasure of consuming the food. It is with this risk assessment in mind that I write this short paper. I describe key studies on competitive exclusion in raw milk. The focus in this summary is on *fresh raw milk*, not a cultured product that introduces additional beneficial bacteria.

- **How to think about the research and your choice**

Before describing the research, it is important to mention what it is we are looking for. Raw milk proponents argue that beneficial properties in raw milk are self-protective and will work to kill pathogens. Raw milk contains lactic acid and, thereby, should work against pathogens to improve the safety of the milk.

But is raw milk self-protective? If I normally consume three-day-old milk, can I be reasonably sure that the pathogens have been killed at that point? What is the actual effect of lactic acid on pathogens in raw milk?

As an example, exercise is well known as a body fat-killer. Larry might walk thirty minutes briskly to the store for his daily treat of raw milk ice cream, burning 400 calories on the round trip through his exertion. Had he driven a car, he might have burned only 30 calories. His walk shows the law-like relationship between exercise and calorie-burning. However, despite Larry's lifestyle choice to walk downtown for his daily ice cream and burn 400 calories, he finds at the end of the month he is still a bit chunky. Dieting consumers interested in Larry's lifestyle need to know not whether Larry's walk is burning calories but whether he ends up, at the end of the month, still fitting into his

pants. He burns more calories walking than he would driving, but he is eating wonderful high-calorie ice cream along the way.

Let's assume that the lactoperoxidase system in raw milk and/or the lactic acid bacteria are as good a killer of pathogens as exercise is of body fat. Knowing that the two are linked still does not give us the answer we need. Raw milk consumers need to know not just whether lactic acid eats away at bad bacteria, but whether the milk ends up pathogen-free in their refrigerator.

If competitive exclusion is to ensure the safety of raw milk, we need to know that raw milk can kill enough bad bacteria that we can be fairly certain that all of the pathogens have died by the time we consume the milk.

From the point of view of the consumer, it is important to ask:

1) If pathogens are killed, are they killed quickly enough that fresh raw milk is safe?
2) If pathogens are killed, are they killed thoroughly enough that I do not consume an infectious dose in my usual daily consumption of milk?

With these questions in mind, I describe key studies on pathogen survival in fresh raw milk.

The BSK Challenge Test

On message boards and blogs, raw milk advocates cite an unpublished study from California as evidence that raw milk kills pathogens.

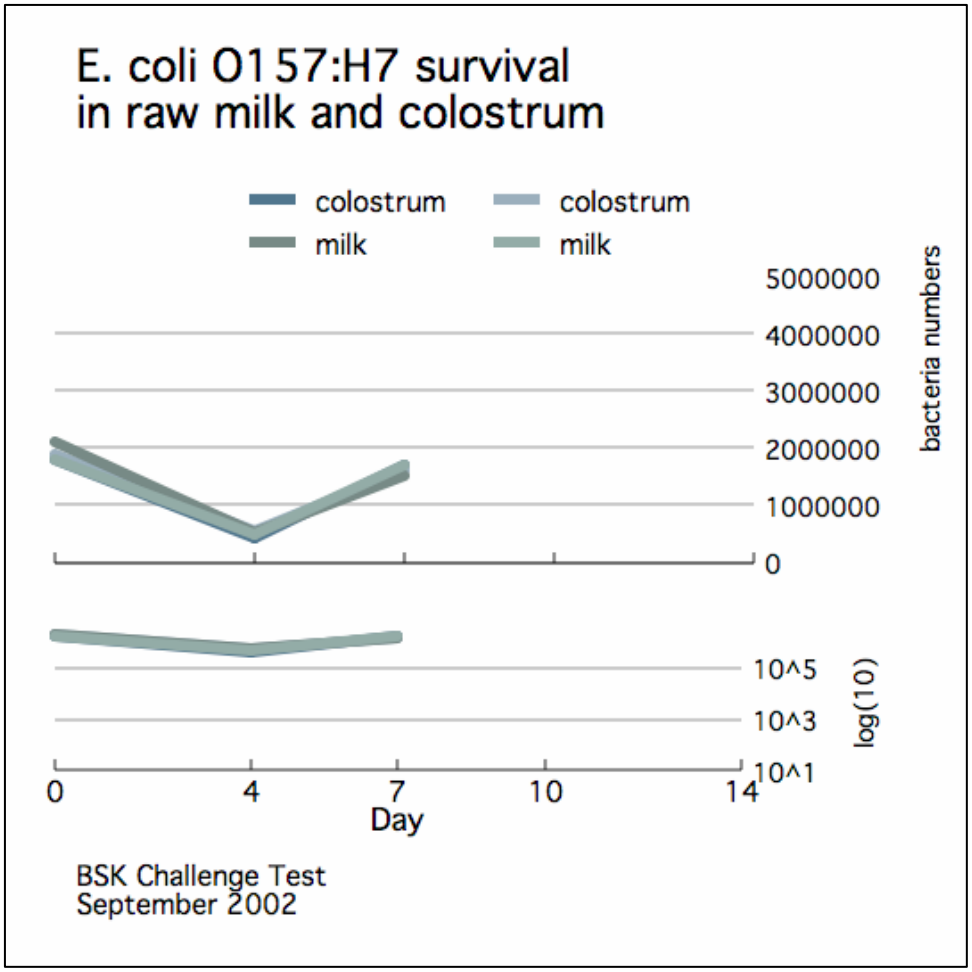
In 2002, a California dairyman took samples of his own raw milk and colostrum to a local laboratory (BSK Laboratories) for a "challenge test." The lab created a pathogen cocktail of *E. coli* 0157:H7, *Listeria*, and *Salmonella*. The technician introduced them into the California raw milk and colostrum, stored them at refrigeration temperatures, and examined change in the numbers of pathogenic cells over a period of one to two weeks.

There are claims on the Internet that the pathogens died off within one day.

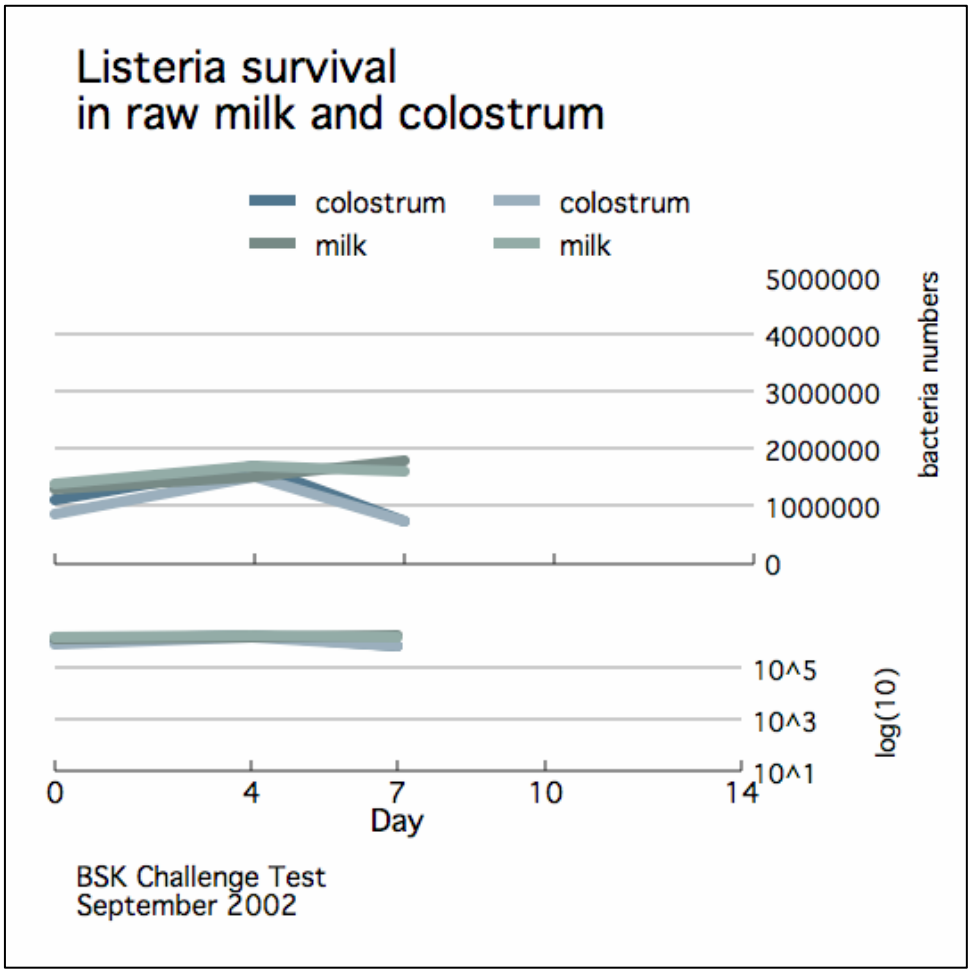
The lab report itself is available on the Internet for consumers to examine. It provides pathogen counts for two raw milk and two raw colostrum samples that the lab tested over time. I present the results on two scales – the absolute bacteria counts as are found in the lab report and a log(10) scale, which microbiologists use to examine substantive changes in the cells in question. (Microbiologists want to see a change of five logs in bacteria counts.) In each graph, the absolute number of cells is presented on the top and the log scale on the bottom.

Two of the pathogens were examined over a one-week period, a third over a two-week period. I present each on a two-week scale for purposes of comparison.

I present the data on the survival of *E. coli* O157:H7 in the figure below. Note that the number of cells did decline between the first day of the test, Day 0, and Day 4. However, when the milk and colostrum were tested on Day 7, the pathogenic *E. coli* had largely recovered. On the microbiologist's log scale of change reported in the lower portion of the graph, the decline and the subsequent increase are but a small change in the data. Microbiologists would like to see a 5-log decline in numbers. The actual decline is less than one log but then the pathogen recovers to its previous level.

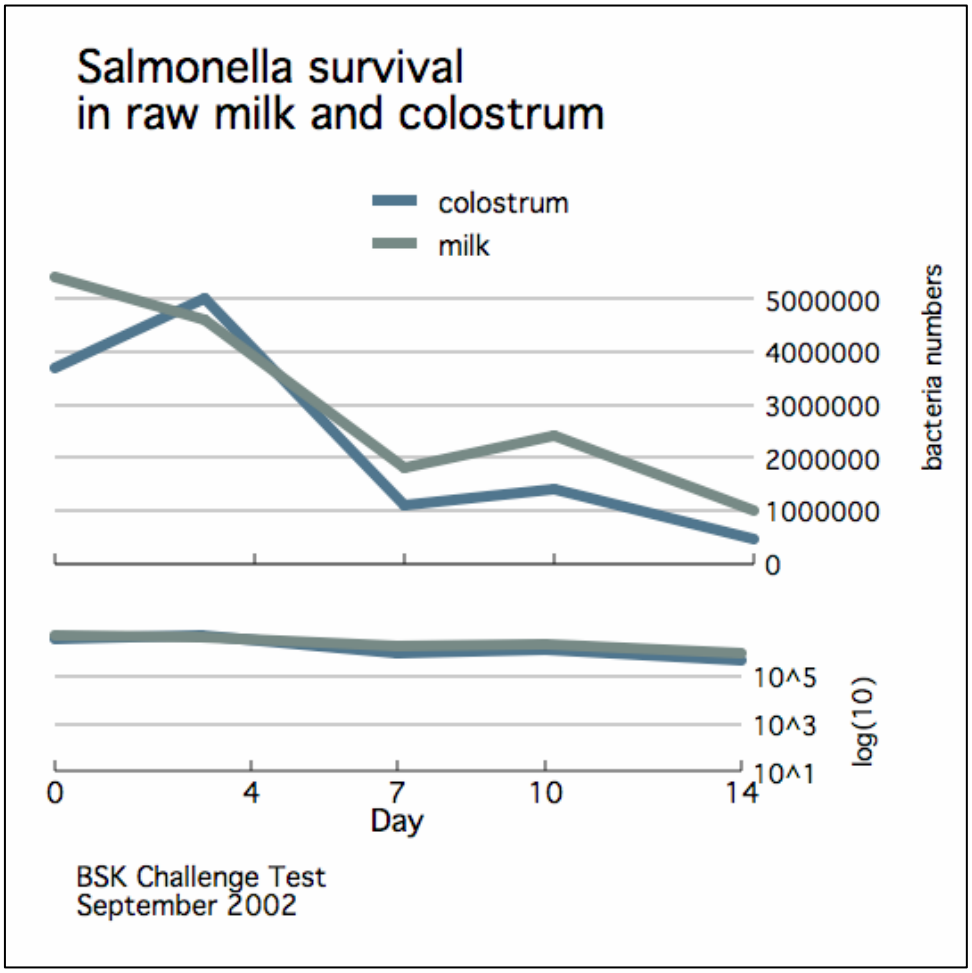


In the *Listeria* case, by Day 4 the *Listeria* increased, though the increase was negligible. By Day 7, the numbers did decline in the colostrum, though the levels are still quite high. If you were to consume the colostrum at that point, you could well get listeriosis.



The lab also examined *Salmonella* but experienced a lab error in taking its baseline measure. Immediately after introducing the pathogenic cocktail into the raw milk and colostrum, the lab was unable to find any evidence of *Salmonella*. In response to this lab error, the lab conducted a separate test on the survival of *Salmonella* in raw milk and colostrum. The *Salmonella* study was conducted separately from the *Listeria* and *E. coli* studies; the *Salmonella* was not part of a pathogen cocktail. The *Salmonella* results, then, follow a slightly different timeline. The lab examined the *Salmonella* over a two-week period and did find a decline in *Salmonella* counts.

Note that *Salmonella* declined from 3,700,000 in raw colostrum on Day 0 to 470,000 on Day 14. In raw milk, *Salmonella* declined from 5,400,000 to 980,000. This change in numbers represents a change of about one log; microbiologists would want to see a change of five logs. I describe these results in more detail in the section on *Salmonella*.



The far more favorable *Salmonella* findings may point to a key research problem with the *Listeria* and *E. coli* portion of the study. The levels of pathogenic bacteria were high and mixed together as a pathogen cocktail. The raw milk had the task of killing not only *E. coli O157:H7* but also *Salmonella* and *Listeria*.

The BSK study has limitations in itself and has largely been misinterpreted by advocates. However, does it provide insight into our key questions?

1) If pathogens are killed, are they killed quickly enough that fresh raw milk is safe?
2) If pathogens are killed, are they killed thoroughly enough that I do not consume an infectious dose in usual daily consumption?

In general, the BSK Study provides no evidence that raw milk and raw colostrum will be made safe by competitive exclusion. However, other studies have been designed more carefully to answer these questions. I describe the findings below.

Campylobacter

If you are exposed to *Campylobacter* bacteria, you may develop diarrhea (possibly bloody diarrhea), fever, nausea, vomiting, headache, stomach pain, and muscle pain. Most cases are mild and do not require the attention of a doctor. On rare occasion it is associated with serious complications or death, particularly if the victim has a suppressed immune system. Approximately 1 in 1,000 persons with campylobacteriosis develop a post-infectious disease called Guillain-Barré Syndrome, which may lead to permanent paralysis. Reactive arthritis is another potential complication following *Campylobacter* infection.

Campylobacteriosis is most often due to consumption of contaminated chicken or other poultry products. However, most outbreaks of campylobacteriosis have been associated with contaminated milk or unchlorinated water. The second largest outbreak of *Campylobacter* in the U.S. actually did involve milk – pasteurized milk in a California prison resulting in over 1,600 illnesses. Numerous *Campylobacter* outbreaks have been linked to raw milk consumption since the 1980s, when the bacterium was first described as a cause of human disease. In recent years, consumption of *raw milk* has been associated with *Campylobacter* illness in Pennsylvania, Colorado, and California. In an extremely rare circumstance, a California woman who consumed raw milk from a herd share program developed a complication of campylobacteriosis, Guillain-Barré, which has left her paralyzed, a condition which I hope will be temporary. Illness from *Campylobacter* bacteria is generally mild but the California case shows that campylobacteriosis can have serious consequences.

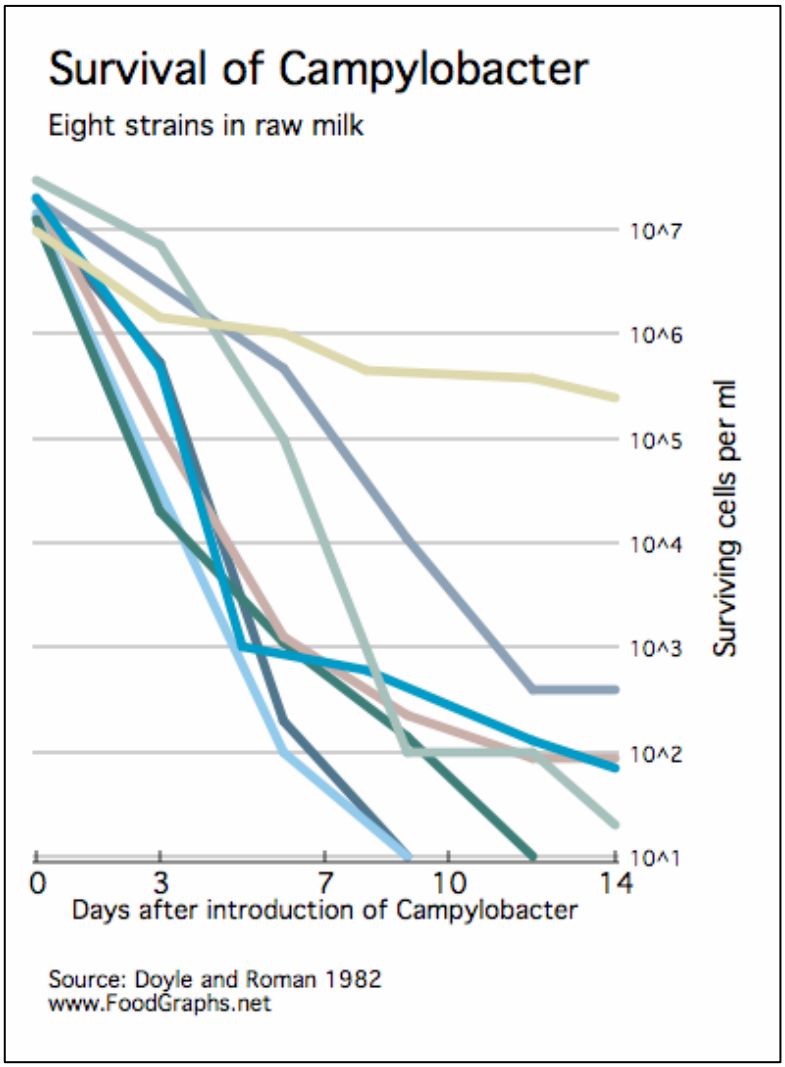
A key study on the survival of *Campylobacter* in raw milk found that the pathogen survives more readily in pasteurized milk than in raw milk (Doyle and Roman). For our concerns, however, we need to examine whether raw milk works hard enough at killing pathogens to ensure consumer safety against *Campylobacter*.

Doyle and Roman examined the survival of eight different *Campylobacter* strains in raw milk. They found a good deal of variation in the survivability of each strain.

In the figure below, I present the cell survival over time, expressed as a log(10) function of the number of bacteria in one milliliter of raw milk. Again, researchers like to see a reduction of five logs of the pathogen. From a baseline of seven logs ($>1.0 \times 10^7$), six of the eight strains showed a 5-log decline over

fourteen days. One strain showed a decline of *almost* five logs while one strain declined less than two logs.

The results are really rather impressive. In their comparison to sterile milk, the authors find that it takes quite a few more days to reduce numbers in sterile milk than in raw milk.

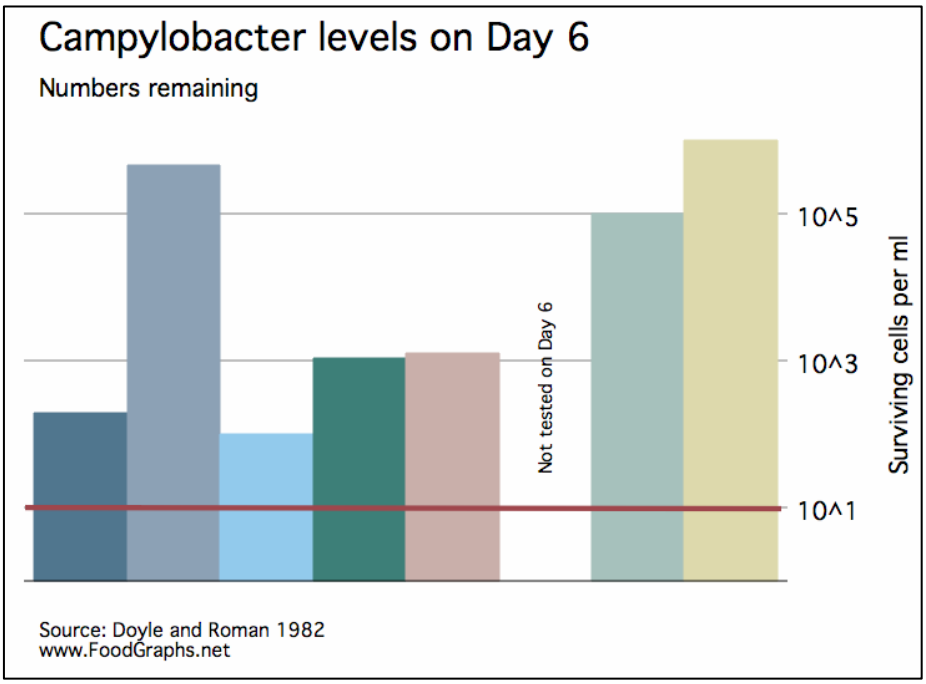


However, we need to ask whether this reduction of *Campylobacter* is sufficient to ensure the safety of raw milk. To do so, let's consider the infectious dose for *Campylobacter* and what levels of *Campylobacter* we would be exposed to if we were to consume milk from the Doyle and Roman experiment.

The infectious dose of *Campylobacter* may be as low as 500 cells, according to feeding experiments where volunteers intentionally consumed different amounts of *Campylobacter*. For our example, let's assume you need to be exposed to 2,000 cells to become sick. There are 240 milliliters in a one-cup serving of milk. Let's assume as well that you like to drink only one cup of raw milk daily.

Imagine that your milk took a day to get to the store, two more days to find its way into your refrigerator, and another three days before you actually consumed it. Most raw milk is likely consumed before it is six days old, but you give the milk a little more chance to work at killing pathogens. You consume it on the sixth day.

On the sixth day, then, we are consuming one cup of raw milk. Each of the 240 milliliters in the one cup has the dose of *Campylobacter* in the Doyle and Roman study. We need each milliliter to contain less than ten *Campylobacter* cells. At ten cells per milliliter, we would be exposed to 2,400 cells in one glass of milk. We might get sick but we might not get sick. However with 2,400 cells, we would likely have at least the *opportunity* to get sick.



In the Doyle and Roman study, by Day 6 when seven of eight samples were tested, none had ten cells or fewer (represented by the red horizontal line in the graph). For the strain that was not tested on Day 6, it had 3 logs of *Campylobacter* cells remaining on Day 5 and 2.8 on Day 8. In the best case scenario, the strain that had died off most rapidly had 100 cells remaining by Day 6. If we were to drink a one-cup portion of that milk, we would have been exposed to 24,000 *Campylobacter* cells, far above the infectious dose. If we consume more than one cup of the milk, our exposure to *Campylobacter* increases as well.

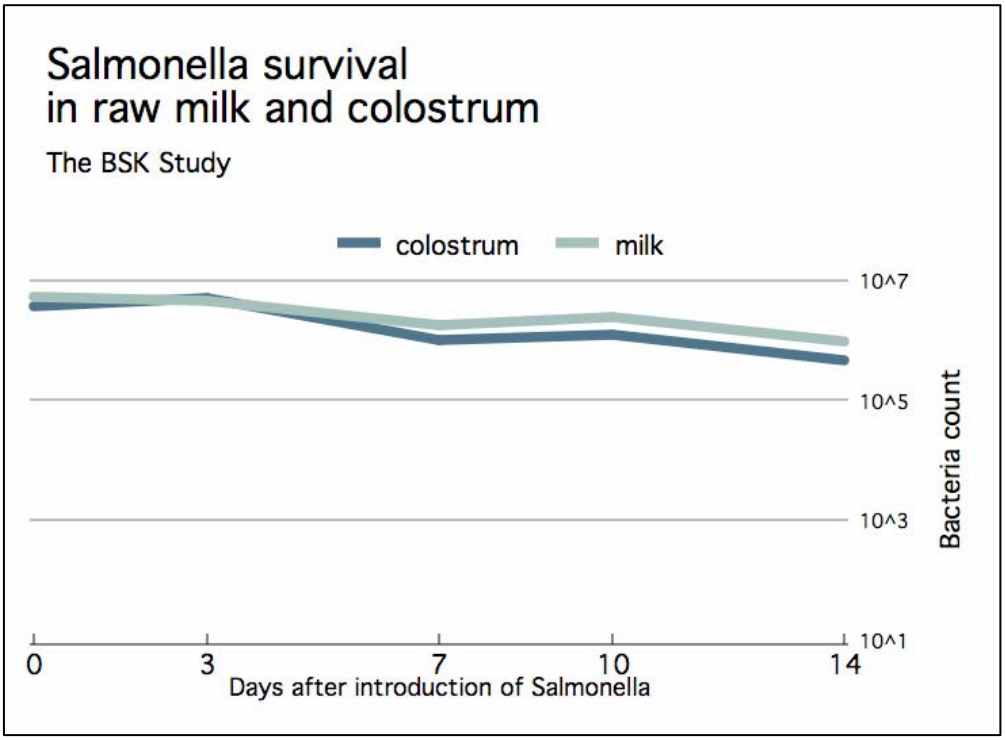
Raw milk proves itself to be a workhorse in the Doyle and Roman study but the study provides no evidence that raw milk works hard enough to keep you from being exposed should you get a contaminated batch of milk. Additionally, *Campylobacter* is a fragile organism requiring special atmospheric conditions ("microaerophilic") compared with other pathogens such as *Salmonella*. Therefore, it is not surprising that over time campylobacters die off in both raw and sterile milk.

Salmonella

A *Salmonella* infection can cause stomach upset, diarrhea, vomiting, chills, fever, muscle pain, and blood in the stool. It is more commonly found in raw and undercooked chicken or eggs, but can be found in raw milk as well.

In the BSK Study presented earlier, we saw a display of the decline in *Salmonella* over a two-week period. I presented the decline in bacteria levels for the BSK Study because that is the way consumers will think about the data when they read the BSK report itself. However, when researchers are examining decline in bacteria numbers, they examine log changes in numbers and want to see a change of at least five logs before they will suggest that any strong, substantive decline has taken place.

With that in mind, I present the BSK *Salmonella* data again, but this time using a log(10) scale. In both the milk and the colostrum samples in the BSK Study, we see a decline of a bit less than one log, not enough of a decline to ensure consumer safety.



In California, a more detailed examination of *Salmonella* survival in raw milk is being conducted by Linda Harris at U.C. Davis. Some early findings from her

study were presented in July 2009 at a raw milk symposium sponsored by the American Veterinarian Medical Association. Unlike many other researchers who collect bulk tank milk to examine pathogen survival, Harris purchased fresh raw milk from a local health food store. On the day of delivery, Harris and her students purchased milk bottled by two California dairies licensed to sell it in retail stores.

Harris also studied fairly low levels of *Salmonella* in milk – two logs of *Salmonella* or hundreds of cells. This low level of *Salmonella* may be closer to real-life contamination events, particularly compared to studies that added seven logs of the pathogen (10,000,000+ cells).

Preliminary findings from Harris' work show that the *Salmonella* numbers do not decrease over a seven-day period when the milk is held at refrigeration temperatures. Held at room temperatures, the *Salmonella* numbers grew from hundreds of cells to hundreds of thousands of cells within two days.

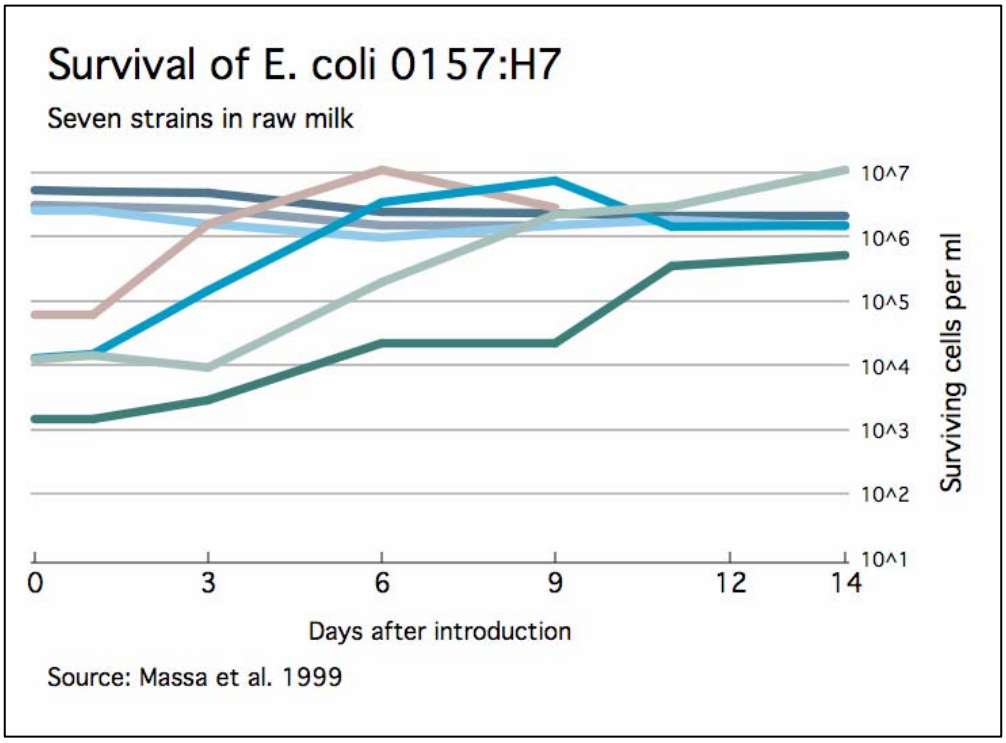
In general, even in raw milk produced for human consumption, we have no evidence that raw milk kills *Salmonella*. In fact, *Salmonella* may grow if the milk is left out on the counter without refrigeration.

E. coli O157:H7

E. coli O157:H7 is a rare pathogenic bacteria, but it has been associated with large-scale foodborne illness outbreaks, particularly in ground beef and fresh produce. Raw milk has been implicated in several *E. coli* outbreaks in recent years, notably in 2005 in Washington state, 2006 in California, and 2008 in Connecticut.

What makes the outbreaks newsworthy is the severity of the reaction by some of the victims. The infection is characterized by bloody diarrhea, vomiting, and severe abdominal cramping. Victims may also develop a complication called hemolytic uremic syndrome (HUS), a blood disease that attacks the kidneys and pancreas. Some victims of HUS have died, others have suffered permanent kidney damage; still others have made a full recovery.

What makes *E. coli* O157:H7 risky for raw milk consumers is that there is little evidence that raw milk kills the bacteria and the infectious dose of the bacteria is extremely low.



In a 1999 study of the survival of *E. coli* O157:H7 in raw milk, Massa and colleagues introduced seven different strains of the pathogen into raw milk

samples. They collected milk from various farms, held the milk at 4°C (39°F) and began the test within five hours of picking up the milk. During the test, they maintained the milk at a temperature of 8°C (46.4°F), just above refrigeration temperatures.

Each of the seven strains of *E. coli* survived the 14-day storage. Four of the seven strains showed an increase of between two and three logs. Likewise, a 1997 study found that the pathogenic *E. coli* increased by 1-2 logs within four days and by 2-3 logs within a week (Wang et al. 1997).

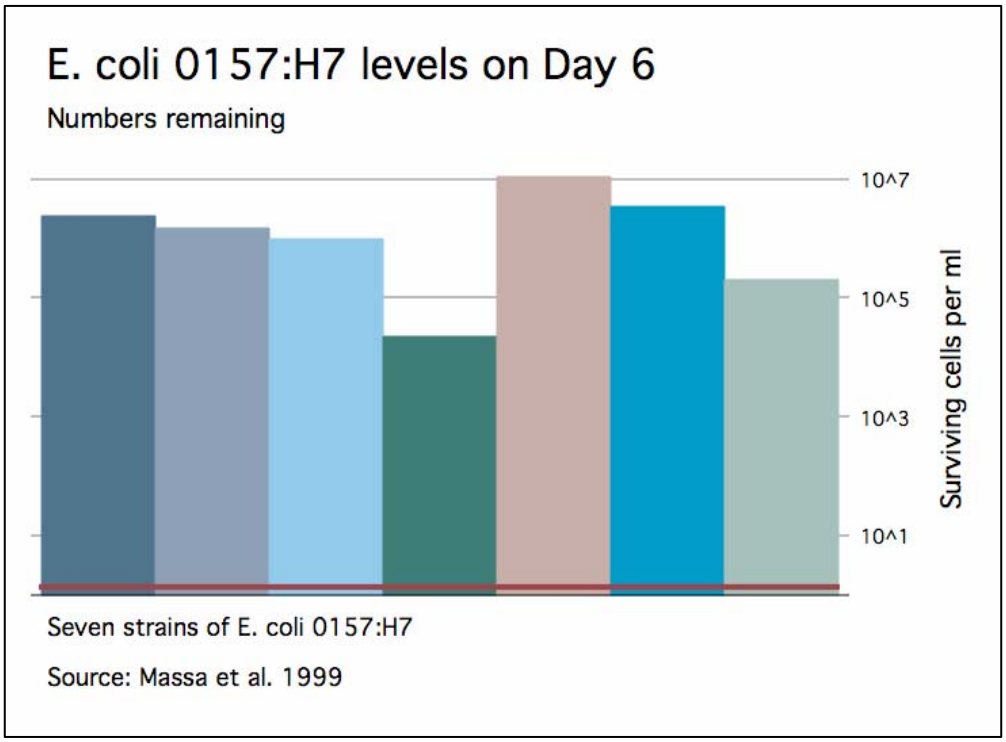
These studies suggest that *E. coli* O157:H7 does not die off in raw milk and may increase over time, particularly if the milk is not kept cold. We are left with a key question: Would we be exposed to an infectious dose if we consumed this milk?

To address this question, let's assume again that you are enjoying an eight-ounce glass of fresh raw milk, milk that is now six days old. The infectious dose of *E. coli* O157:H7 is under 100 and perhaps even under 50 cells (studies from past outbreaks suggest it may be as low as 10 cells). Your 8-ounce glass of milk contains 240 milliliters of milk. You could afford to ingest about one *E. coli* O157:H7 cell for every five milliliters of milk, about 1/5 of a cell in each milliliter

In the figure below I plot the number of cells remaining on Day 6 in the study. Using the Massa study data, consider the levels of *E. coli* O157:H7 for each strain at Day 6. The first strain in the graph, plotted on the far left, has cells counts over six logs or 24,000,000 *E. coli* O157:H7 cells per milliliter. I draw a red line at the bottom of the graph in an effort to show how much of this pathogenic *E. coli* we may be able to ingest without getting sick. In reality it is difficult to represent 1/5 of a cell on a graph. The fact is that the pathogen levels on Day 6 of any of these strains could make any of us quite sick.

Of course, the researchers started with very high levels of the pathogen. Perhaps with lower levels of *E. coli* O157:H7 these results would look much different, but we have no reason to expect such an outcome. With the low infectious dose of *E. coli* O157:H7 and the damage it can do, particularly if the victim develops HUS, we have reason to proceed with caution and assume that the raw milk will not kill enough of the *E. coli* cells to make a contaminated batch safe. We cannot rely on competitive exclusion to protect us from this particular pathogen.

Because of the low infectious dose and the severity of the infection if you get it, scientists have developed a vaccine that keeps this pathogen from being shed in the manure of cattle. I realize that vaccines for cows and for people are anathema to most raw milk consumers, but this particular vaccine may be one to watch given the apparent survival ability of *E. coli* O157:H7 in raw milk.

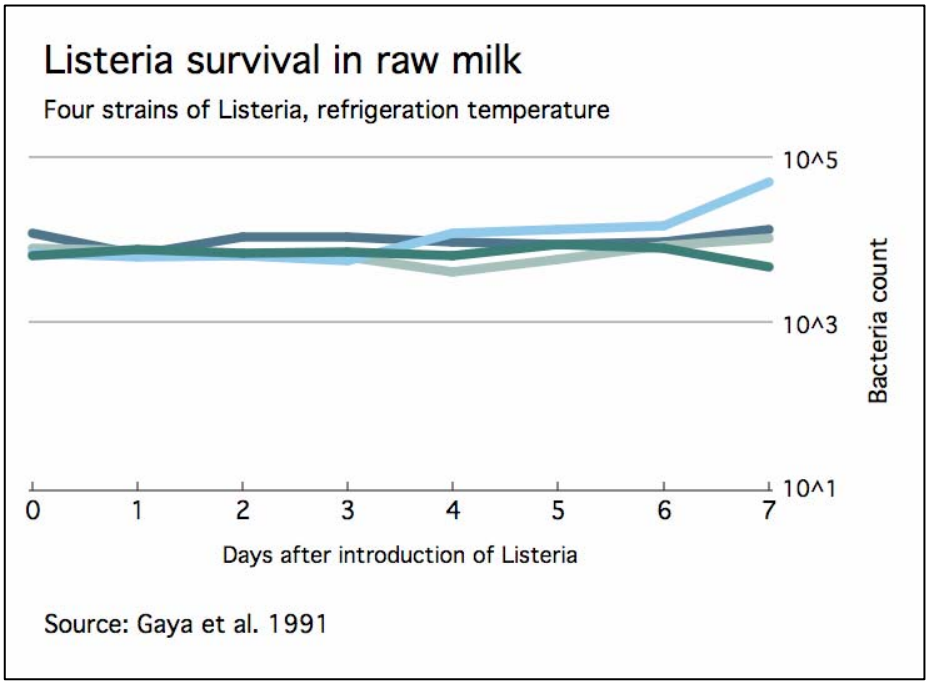


Listeria monocytogenes

Listeria can cause mild flu-like symptoms in people who are exposed. People with more serious reactions may develop meningitis, encephalitis, or septicemia. In pregnancy, if the *Listeria* bug crosses the placenta, an infection will develop in the fetal sack. The body then protects itself from the infection by expelling the baby and causing a miscarriage, stillbirth, or premature birth, depending on the stage of the pregnancy. Raw milk is one of many foods pregnant women are told to avoid because of the risk of *Listeria* contamination. (See the Listeria food list provided by the USDA.)

Many people do, however, consume raw milk in pregnancy and at other stages in life. The question for us is whether we can be assured that the lactoperoxidase system in raw milk will protect us against various strains of *Listeria*.

The evidence on the survival of *Listeria monocytogenes* in raw milk is mixed. A 1999 study found that raw milk did work against *Listeria*. Researchers introduced four logs of *Listeria* into raw milk, held the milk at 99° F, and could not detect the pathogen 56 hours later. However, held closer to refrigeration temperatures (40-45° F), the *Listeria* numbers grew. In their study, they did compare *Listeria* survival in raw milk to pasteurized milk and found that raw milk was the better performer (Pitt et al. 1999).



However, in a study of four different strains of *Listeria* (displayed above), researchers found no change in the number of cells over a seven-day period when the milk was held at 4° C (or about 39° F). Perhaps the differences in findings are due to the different strains of *Listeria*. In any case, the research on the survival of *Listeria* in raw milk is mixed.

The infectious dose is unknown according to the FDA, but it speculates that it may be under 1,000 cells, or three logs. Exposure to the milk used in the Gaya study in the figure above would likely be an infectious dose. In the 1999 study not pictured we would be exposed to an infectious dose for about the first two days of the life of the milk.

I should make a distinction between getting an infectious dose in the first place and having a pregnancy-related complication. In a study of pregnant guinea pigs, researchers found that it took one cell in the placenta to begin an infection in the uterus (Bakardjiev et al. 2006). What we do not know is how much exposure we need in pregnancy for a cell to cross the placenta. Apparently crossing the placenta is unusual, but when it does happen, it appears that a chain reaction begins that ends with the body expelling the contents of the uterus.

In general, some strains of *Listeria* may well be killed off in milk within the first couple of days. However, some strains appear to be more resilient to the lactoperoxidase enzyme in milk.

Is raw milk more protective than pasteurized milk?

If you arrived at my house with a bottle of raw milk and a bottle of pasteurized milk and announced that you had introduced a pathogen into each bottle the week before, I would pass on both options. If you forced me to choose, the choice would be pretty simple: I would choose the raw milk.

I would choose the raw milk over the pasteurized because there is evidence that raw milk is more of a heavy-lifter in the pathogen-killing department. The Doyle and Roman study on *Campylobacter* compared its survival in raw and pasteurized milk. In the strain that they tested (not the one that never did die off), they found that the pathogen survived only one week in the raw milk, whereas it took two weeks to die off in the pasteurized milk.

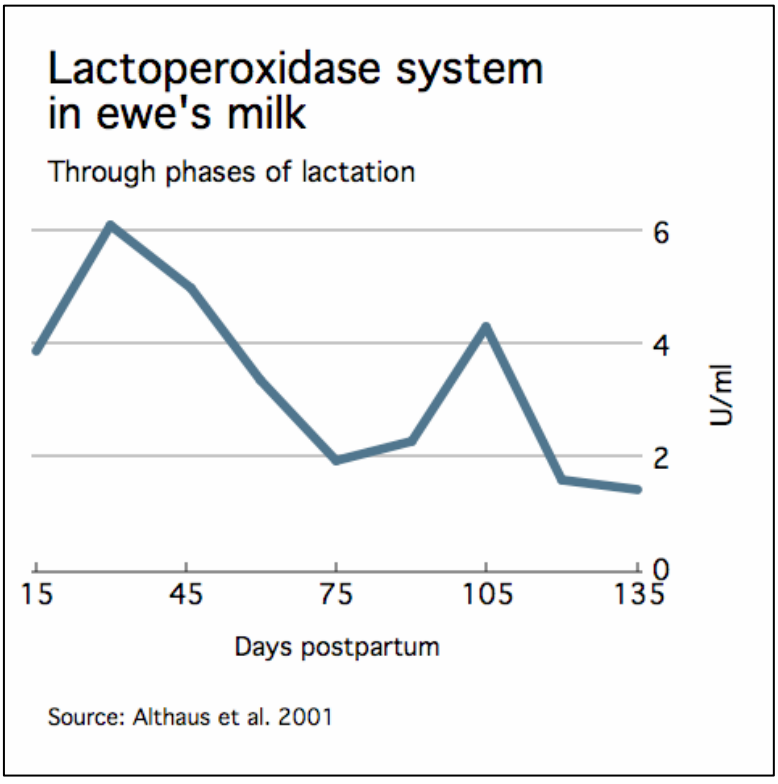
The 1999 *Listeria* study found that *Listeria* does persist in pasteurized milk and dies off in raw milk (Pitt et al. 1999)

There is a good bit of truth in what has become something of an urban legend status on the Internet: raw milk is a better pathogen-fighter than pasteurized milk. We know that contamination can occur in milking and in bottling. Now we also know that raw milk's pathogen-fighting muscle is not strong enough to ensure that consumers will not get sick if they draw a bad card and get a contaminated batch.

Can we count on raw milk to kill pathogens?

Raw milk does contain an enzyme called lactoperoxidase that works against pathogens. Where we have seen a decline in multiple strains of *Campylobacter*, the credit is likely due to the lactoperoxidase enzyme. However, *Campylobacter* also declines rapidly in sterile milk, probably because it is a fragile organism that does not survive well outside the animal host's intestinal tract.

Yet we see a lot of variation in the data in this summary. We have seen evidence that raw milk reduces the numbers of some strains of *Campylobacter* but not others. Refrigerated raw milk may keep *Salmonella* from growing but at room temperature, the *Salmonella* may grow like crazy. *Listeria* may decline in raw milk or it may not. At warmer temperatures, *Listeria* may grow a bit. *Campylobacter* may die at warmer temperatures. *E. coli* O157:H7 may grow a bit in raw milk and it may even grow a good bit.



The evidence suggests that we really cannot count on raw milk killing enough pathogens to ensure its safety. One reason may well be that we cannot expect the same level of the lactoperoxidase enzyme in all milk. Researchers examined the enzyme in ewe's milk through the first four months of lactation. Note in the figure at right that the enzyme level peaked at about 30 days postpartum, but generally showed a great deal of variability. The milk you are drinking may come from any of these stages of lactation (or likely some average of the stages if your milk comes from multiple cows).

Nature provides us with variation in pathogens, in their ability to survive raw milk, and in raw milk's protective enzyme system. This variation suggests that we cannot make claims one way or another about the safety of fresh raw milk (that is not cultured) at least insofar as it relates to competitive exclusion.

I introduced this paper with two questions:

1) If pathogens are killed, are they killed quickly enough that fresh raw milk is safe?
2) If pathogens are killed, are they killed thoroughly enough that I do not consume an infectious dose in my usual daily consumption?

The variation in research findings and the variation in milk enzyme levels themselves suggest that the answer to both of these questions is "Probably not."

Contrary to a good bit of information on the Internet that raw milk is self-protective and kills pathogenic bacteria, the world provides us with no guarantees.

There are no guarantees that any food we consume is safe so we do need to have adequate information to make the best choice given our circumstances. Of course, there are hosts of other factors consumers use to decide whether to drink raw milk which are beyond the scope of this paper. If this one narrow topic -- competitive exclusion – is a factor in your decision to consume raw milk, I hope that this paper has been helpful to you.

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