Survival and Growth of Bacterial Pathogens on Raw Meat During Chilling

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Introduction

Intact tissues from healthy animals are sterile. However, when these animals are slaughtered, bacteria from the hide, the gut, or the processing environment may contaminate the surfaces of meat. This occurs despite of washing animals before slaughter, various treatments to clean carcasses during processing, and programs to keep the environment clean. Some of these organisms are spoilage bacteria while others are pathogenic to humans.

Many bacteria are unable to grow at low temperatures but can survive storage in the cold. Generally, numbers of viable bacterial cells decrease with time during refrigerated storage *(1, 3, 4, 21)*. Other bacteria, including *Listeria*, *Yersinia*, some strains of *Clostridium botulinum* and *Bacillus cereus*, and some spoilage organisms, are psychrotrophic and can grow at refrigeration temperatures (Table 1). However, growth during chilled storage is usually slow (*18*).

Several research papers have described protocols and experimental results for determining the hygienic adequacy of cooling processes by considering published data on growth rates of pathogens and the temperature history of the meat *(2, 9–16)*.

Temperature is not the only factor limiting growth of bacteria. Experiments have shown that bacteria grow more slowly on meat at a more acidic (lower) pH *(25)*. Washing carcasses with organic acids, trisodium phosphate, or alkaline solutions significantly decreases pathogen levels *(5, 6)*. Some pathogenic bacteria are not very good competitors and grow much more slowly in the presence of other bacteria that may be present on meat. Air cooling process may cause drying at the surface of the meat and this inhibits bacterial growth. For these reasons, one cannot simply extrapolate growth data from bacteria grown in the lab to commercial cooling processes.

Table 1. Temperature Limits for Foodborne Bacteria in Raw Meat

	Growth temperatures		Time at test temperatures		
Bacteria	**Minimum**	**Test**	**Lag**	**Generation**	**Ref.**
Bacillus cereus	41°F	41°F		8.3 hr	*(19)*
Campylobacter jejuni	86°F				*(19)*
Clostridium botulinum nonproteolytic	37.9°F				*(19)*
Clostridium botulinum proteolytic	50°F				*(19)*
Clostridium perfringens	53.6°F	53.6°F		11.5 hr	*(19)*
Escherichia coli SF	44.6°F	46.8°F	40 hr	6.9 hr	*(19, 26)*
E. coli O157:H7		35.6°F		no growth	*(1)*
E. coli O157:H7, pH 5.7		53.6°F	16.2 hr	6.0 hr	*(27)*
E. coli O157:H7, pH 6.3		53.6°F	2.78 hr	3.9 hr	*(27)*
Listeria monocytogenes	32°F	39.2°F		22.8 hr	*(19)*
Listeria monocytogenes		39.2°F		9.3 hr	*(22)*
Salmonella typhimurium	41°F	50°F	45 hr	9.65 hr	*(19, 26)*
Staphylococcus aureus	44.6°F				*(19)*
Yersinia enterocolitica	30.2°F	41°F		16.53 hr	*(18, 19)*
Yersinia enterocolitica		50°F		12.73 hr	*(18)*

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BEEF

Potential pathogens (*Staphylococcus aureus, Clostridium perfringens*, and fecal coliforms) were more numerous on hot-boned beef cooled at slower chilling rates (9 and 12 hours to 69.8°F) than on beef chilled more rapidly (3 and 5 hours to 69.8°F). The authors recommend chilling hot boned meat to 69.8°F within 3–9 hours after fabrication with continuous chilling to <50°F within 24 hours *(8)*.

Temperature histories of hot-boned beef were used to predict the hygienic adequacy of the cooling process. Chilling of the packaged meat was found to allow a higher average proliferation of *E. coli* (9.3 generations) than the Good Manufacturing Practice for beef side cooling (6.8 generations). After an upgrade of the cooling facility, meat was cooled faster and the average calculated proliferation of *E. coli* was 7.1 generations. Observed multiplication of *E. coli* in cooling cartons of meat agreed with calculated proliferation within 1 generation *(23)*.

During 10 days storage under commercial chilling conditions, the proportion of psychrotrophic bacteria isolated from beef surfaces gradually increased from <50% to about 90% as mesophilic bacteria correspondingly decreased. Species isolated at the end of storage included *S. aureus*, *Bacillus* sp., coliforms, micrococci, and *Pseudomonas* sp. *(20)*.

Cooling of beef surfaces to <44.6°F in two commercial spray chillers was determined to take an average of 12.8 hr in one cooler and 10.9 hr in the other. Cooling rates combined with data on growth of *E. coli* at various temperatures indicated that growth of this bacterium would average 6.8 and 4.7 generations, respectively *(10)*.

PORK

Examination of pork carcasses immediately after slaughter and then after 20 hours of chilling at 39.2°F revealed a prevalence of *Salmonella* sp. of 29% that was not affected by chilling. Fewer samples were contaminated with *Campylobacter coli*. Cooling tended to decrease the number of positive samples. Spraying carcasses with 2% lactic acid reduced counts of both of these bacteria but did not eliminate them *(7)*.

Contamination of pork carcasses with several foodborne pathogens was measured at several steps during processing at 3 slaughter plants *(24)*. Percentages of positive samples containing *Salmonella* spp., and *Yersinia enterocolitica* declined during 24 hours of chilled storage while positive samples of *Staphylococcus aureus* increased and of *Listeria monocytogenes* remained the same. The increase in *S. aureus* was believed to be the result of increased human handling because this bacterium is usually carried by humans. Frequency of isolation of *S. aureus*, *Y. enterocolitica*, and *L. monocytogenes* also increased during 36 days of storage of loins that were vacuum packaged and stored at 35.6°F.

A spray-cooling process for pig carcasses, using 20-sec sprays of water (41°F) at 10 min intervals, has been evaluated for hygienic performance *(12)*. Prior to the spray cooler, carcasses were subjected to a blast of air at –4°F for 60 min. Temperatures measured at various sites on the surface, including the aitch-bone pocket, which has been determined to be the slowest cooling area, reached <44.6°F in 13 of 15 carcasses by the time cooling was finished (minimum of 14.8 hr). Although temperature history data indicated that *E. coli* could proliferate by up to 15.9 generations during cooling, actual plate counts of *E. coli* in samples taken at entry and exit from the cooler showed no significant change in cell numbers during cooling. Other factors than temperature, for example surface drying, affect the viability of bacteria.

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Comparison of conventional spray-chilling with spray-chilling preceded by a freezing tunnel indicted that temperatures were lower and potential proliferation of *E. coli* on carcasses was less when carcasses were first cooled by the freezing air. Coolers usually have warmer and cooler areas depending on air flow and this freezing blast apparently keeps temperatures consistently low *(11)*.

LAMB

An air cooling process for lamb carcasses, using air blown from refrigeration coils at a temperature of about 32°F, has been evaluated for its hygienic performance *(12)*. Temperatures measured at various sites on the surface, including the aitch-bone pocket (which has been determined to be the slowest cooling area) reached <44.6°F by the time cooling was finished (minimum of 17.5 hr). Data on rate of decreasing temperatures were combined with information on bacterial growth to predict that *E. coli* could proliferate from 0.2 to 7.1 generations during cooling. However, actual measurements of *E. coli* per 100 cm^2 of carcass surface revealed that there was a decrease from 2.12 at entry to 0.82 at exit from the chiller. Other factors besides temperature, for example surface drying, affect the viability of bacteria.

A process hygiene index (PHI) was proposed for establishing the adequacy of lamb cooling processes *(17)*. Carcasses were loaded onto a cooling floor and temperatures were reduced to about 44°F during 14 hours. Temperature histories were recorded and combined with data on growth of *E. coli* to produce a PHI for the process. Meat intended to be frozen until purchase by the consumer could have a higher acceptable PHI.

SUMMARY

Rapid chilling of animal carcasses after slaughter is important for retarding the growth of both pathogenic and spoilage bacteria. Chilling will not destroy these bacteria although viable cells of many species decrease with time during refrigerated storage. Other types of foodborne pathogens, including viruses and parasites, do not grow on meat of slaughtered animals and therefore are not a concern in evaluating the hygienic efficiency of cooling processes.

Psychrotrophic bacteria can grow at low temperatures, even in refrigerators. The most important pathogenic psychrotrophs for the meat industry are *L. monocytogenes* and *Y. enterocolitica*, both of which can grow at temperatures as low as 30°F. Psychrotrophic strains of *B. cereus* are mainly found in dairy products while nonproteolytic *C. botulinum* are usually isolated from seafood. Nevertheless these latter two species are present in the environment and some strains may be (or become) capable of growth on meat.

Although psychrotrophs can grow at low temperatures, there may be a long lag phase of several hours before growth begins and a relatively long generation time at refrigeration temperatures. Given enough time, significant growth may occur. But if meat is kept at a low temperature (which permits growth of pathogens) for a relatively short time, then there may be no significant growth. Other factors, such as the drying effect on air-cooled carcasses, the presence of other bacteria, the pH of the meat, and carcass washing procedures will also affect the growth rate of pathogens.

All of these factors should be considered in evaluating the safety of chilling processes. Several researchers have conducted studies of cooling processes in slaughterhouses and have proposed and tested methods for determining their hygienic efficiency.

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