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Microbiological Safety of Commercial Prime Rib Preparation Methods: Thermal Inactivation of *Salmonella* in Mechanically Tenderized Rib Eye†

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ABSTRACT

Boneless beef rib eye roasts were surface inoculated on the fat side with ca. 5.7 log CFU/g of a five-strain cocktail of *Salmonella* for subsequent searing, cooking, and warm holding using preparation methods practiced by restaurants surveyed in a medium-size Midwestern city. A portion of the inoculated roasts was then passed once through a mechanical blade tenderizer. For both intact and nonintact roasts, searing for 15 min at 260°C resulted in reductions in *Salmonella* populations of ca. 0.3 to 1.3 log CFU/g. For intact (nontenderized) rib eye roasts, cooking to internal temperatures of 37.8 or 48.9°C resulted in additional reductions of ca. 3.4 log CFU/g. For tenderized (nonintact) rib eye roasts, cooking to internal temperatures of 37.8 or 48.9°C resulted in additional reductions of ca. 3.1 or 3.4 log CFU/g, respectively. Pathogen populations remained relatively unchanged for intact roasts cooked to 37.8 or 48.9°C and for nonintact roasts cooked to 48.9°C when held at 60.0°C for up to 8 h. In contrast, pathogen populations increased ca. 2.0 log CFU/g in nonintact rib eye cooked to 37.8°C when held at 60.0°C for 8 h. Thus, cooking at low temperatures and extended holding at relatively low temperatures as evaluated herein may pose a food safety risk to consumers in terms of inadequate lethality and/or subsequent outgrowth of *Salmonella,* especially if nonintact rib eye is used in the preparation of prime rib, if on occasion appreciable populations of *Salmonella* are present in or on the meat, and/or if the meat is not cooked adequately throughout.

Prime rib is a high quality beef roast characterized by its richness, flavor, and juicy texture. It is prepared by hand rubbing the meat with salt and spices, followed by searing and a slow-cooking process to achieve a rare or medium-rare degree of doneness, and is finished with a warm holding period (e.g., 1 to 12 h at 60.0°C) until it is sliced and served *(29)*. Although a beef rib eye is intrinsically of high quality, pathogens such as *Salmonella* or Shiga toxin–producing *Escherichia coli* (STEC), notably serotype O157:H7 strains, may on occasion reside on raw beef, albeit at relatively low populations, and may pose a food safety risk due to the low cooking temperatures and extended warm holding periods used to prepare prime rib. For the past 35 years, most food safety performance standards for cooking meat products, including roasts, were, for better or for worse, based on lethality for *Salmonella (24)*. Despite existing standards and guidelines, there have been a few salmonellosis outbreaks attributed to prime rib, including a handful of outbreaks in the mid-2000s *(13, 14)*. Also worth mentioning are outbreaks in Connecticut in the mid-1980s, one of which affected 18 people who ate or worked at the incriminated restaurant and a second outbreak that possibly caused the death of five people at a health care facility for the elderly *(34)*. Likewise, undercooked roast beef was implicated in a *Salmonella* infection outbreak in 1996 *(40),* and there was also a cluster of salmonellosis outbreaks attributable to precooked beef roast in the late 1970s *(10–12)*. Although similar to prime rib, roast beef is prepared somewhat differently by first slow cooking, usually under vacuum and wet conditions, to an internal temperature of about 43.3°C (110°F), followed by an additional heating period of up to 3 h at slightly higher temperatures before slicing and serving. Shapiro and colleagues *(40)* speculated that puncturing an intact roast with a temperature probe or slicing steaks from an intact roast can transfer undesirable microbes from the surface to the interior of the meat. Internalization of pathogens, along with inadequate cooking and/or improper handling, most likely contributed to the outbreaks mentioned above attributed to salmonellosis from tainted prime rib and roast beef.

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Prime rib is primarily a food service item that is most frequently cooked by chefs at restaurants rather than at a meat processing operation or in the home. The recommendations set forth in the U.S. Food and Drug Administration Food Code *(44)* form the basis for state and local food safety regulations for the food service industry. Accordingly, raw animal foods should be "cooked to heat all parts of the food to a temperature and for a time" that complies with the cooking methods detailed under section 3-401 of the Food Code. Examples germane to the present study include cooking mechanically tenderized meats to a minimum temperature of 63°C (145°F) and then holding the product for 3 min, whereas whole beef roasts weighing ≥4.5 kg (10 lb) should be cooked in a convection oven maintained at ≥121°C (250°F) until all parts of the roast achieve a minimum temperature of 54.4°C (130°F), and then the product should be held for up to 112 min *(44)*. While it is not a current or common practice to use nonintact beef for the preparation of prime rib, the food service industry and restaurants may be interested in using nonintact beef in the foreseeable future because of its enhanced tenderness and more consistent eating quality. The majority (94%) of steaks and roasts used by restaurants and institutions may be subjected to mechanical tenderization *(20)*. George-Evins et al. *(21)* conducted an industry survey of 241 members of a trade organization of meat processors and reported that 76 of 90 respondents used blade tenderizers, and 38% of these respondents blade tenderized about 80% of their rib cuts, using an average of 1.4 passes. Although both quality and consistency are enhanced by mechanical tenderization *(21),* safety may be reduced; internalization via tenderization of surface microbes, including low populations of pathogens if present, may raise concerns even for products that are processed and stored properly. The U.S. Department of Agriculture, Food Safety and Inspection Service (USDA-FSIS *(43)*) has communicated requirements for providing product labels that identify meat as being (mechanically) tenderized and includes product specific cooking instructions to eliminate STEC and presumably other pathogens, such as *Salmonella*.

Since 2000, at least five outbreaks have been associated with contamination of nonintact beef products by STEC *(15, 16, 27, 42)*. Considering the relatively high prevalence of *Salmonella* associated with beef cattle, including ground beef and other whole and nonintact beef products *(2, 6–8),* it is highly probable that this organism can also be transferred to raw beef products during slaughter and further processing of the harvested meat. The presence of pathogens on carcasses and on raw beef in general could represent a risk to consumers if either intact or nonintact beef were undercooked and/or improperly handled or held. Several studies have been conducted on thermal inactivation of *Salmonella* in various meat products, all of which concluded that proper cooking will inactivate this pathogen *(4, 18, 28, 35, 36, 45)*. Preparation of prime rib typically includes a warm holding step where the cooked roast may be held for extended periods (e.g., 1 to 12 h) at temperatures (e.g., 48.9°C) slightly above the maximum growth temperature for several foodborne pathogens, including *Salmonella* (i.e., 46.2°C). Thus, if some cells survive the searing and cooking processes used to prepare prime rib and/or if some cells are transferred into the deeper tissues of the meat by mechanical tenderization, in some instances these cells may survive and grow during the extended warm holding period, especially when the temperature of the meat fluctuates somewhat. Temperature fluctuations may occur when chefs open the holding ovens throughout the day to slice steaks from the cooked rib eye to serve customers. Opening the oven and/or removing a rib eye roast to slice steaks for patrons can result in a temporary reduction in both the temperature of the oven and the temperature of the rib eye, thus increasing the risk of pathogen survival or growth. The objectives of this research were to (i) characterize prime rib preparation methods (i.e., searing, cooking, and holding) practiced by restaurants, (ii) quantify translocation of surface-inoculated *Salmonella* into the deeper layers of the meat following blade tenderization of rib eye roasts, and (iii) validate thermal destruction and/or survival of *Salmonella* during the preparation of intact and nonintact rib eye.

MATERIALS AND METHODS

Survey of practices for preparing prime rib in restaurants. Six restaurants (two of which belong to the same local chain of restaurants) within a medium-size Midwestern city in the United States were surveyed to gain insight into their methods for preparing prime rib *(9)*. An initial visit to each restaurant involved discussions with the chef concerning the prime rib preparation method, followed by three subsequent visits to each of the restaurants to measure the temperatures attained in the meat during each stage of preparation. The temperature of prime rib was recorded using a type K thermocouple connected to a data logger (model EL-USB-TC-LCD, Lascar Electronics, Salisbury, UK). The thermocouple was inserted into the approximate geometric center of the rib eye, and product temperature was measured from the time the meat (one roast per each of three visits to each of the six restaurants) was placed in the searing oven through to cooking and warm holding, and then onward until it was served to the last customer each day in the restaurant. Chefs commonly periodically checked the temperature of the meat with a dial stem thermometer.

Bacterial strains. The following five rifampin-resistant (100 μg/ml; Sigma Chemical Company, St. Louis, MO) *Salmonella* isolates were used in this study: *Salmonella* Typhimurium MFS 248 (hog carcass isolate), *Salmonella* Typhimurium MFS 330 (hog carcass isolate), *Salmonella* Copenhagen MFS 3446 (pork isolate), *Salmonella* Typhimurium MFS 3447 (FSIS OB060362, pork sausage isolate), and *Salmonella* Typhimurium MFS 3448 (H3380, clinical isolate). The isolates were maintained and cultured and the cocktail was prepared essentially as described previously *(25, 39)*.

Meat inoculation. Vacuum-packaged boneless rib eye lip-on (institutional meat purchase specification no. 112A; ca. 8 to 9 kg [18 to 20 lb] each) subprimals were purchased from a wholesale distributor and stored at 4°C for up to 5 days at the USDA Agricultural Research Service (ARS), Eastern Regional Research Center (ERRC) (Wyndmoor, PA). For each of two trials conducted for intact or nonintact roasts, five subprimals were inoculated on the fat side surface of the meat with 50 ml of the *Salmonella* cocktail to achieve an initial inoculation level of ca. 5.7 log CFU/g

essentially as described previously *(32, 38, 39, 41)*. For nonintact subprimals, one of the five inoculated roasts was used to evaluate translocation of *Salmonella* and to procure uncooked (control) steaks, and the remaining four roasts were used to evaluate thermal destruction of *Salmonella* during the subsequent preparation of prime rib. For intact (nontenderized) subprimals, one of the five roasts in each of two trials was used to procure uncooked (control) steaks, and the remaining four roasts were used to monitor the fate of *Salmonella* during the subsequent preparation of prime rib. The meat was gently massaged to facilitate distribution of the inoculum. Intact roasts were then stored overnight at 4°C. In contrast, after ca. 30 min at 4°C to allow for better attachment of the pathogen to the product, the nonintact roasts inoculated with *Salmonella* were tenderized as described below.

Mechanical tenderization. One set of inoculated subprimals was passed once through a blade tenderizer (series TC 7000M, Ross Industries, Midland, VA) with the fat side (inoculated side) facing up essentially as described previously *(30, 33)*. After blade tenderization, the meat was placed on trays, covered with aluminum foil, and stored overnight under refrigeration to allow for bacterial attachment *(30, 33)*.

Translocation of *Salmonella* into rib eye roast during tenderization. In each of two trials, six core samples were obtained from one inoculated blade tenderized subprimal using an alcohol-sanitized cylindrical stainless steel coring device (2.54 cm diameter) as described previously *(30, 39)*. Each core sample was divided into six segments (segments 1 to 4 were ca. 1 cm thick, and segments 5 and 6 were ca. 2 cm thick). Segment 1 encompassed the top-most surface of the meat (i.e., fat side, inoculated side), and segment 6 encompassed the bottom-most surface (i.e., lean side).

Searing, cooking, and holding of roasts. Temperature data collected at the six restaurants surveyed were used to select the relevant time-temperature schedules to prepare (inoculated) prime rib in the present study at the ERRC by first searing at 260°C (500°F) for 15 min and then cooking at 121.1°C (250°F) to instantaneous internal temperatures of 37.8°C (100°F) for intact (process A) and nonintact (process C) roasts or of 48.9°C (120°F) for intact (process B) and nonintact (process D) roasts. Internal temperatures of the meat and the air temperature of the oven were monitored using thermocouples (type J, Omega Engineering Inc., Stamford, CT) connected individually to an eight-channel digital panel temperature indicator (model 500T, Doric Instruments, VAS Engineering Inc., San Diego, CA). To measure the air temperature, one thermocouple was positioned just inside of the oven, whereas to measure the meat temperature, one thermocouple was inserted into the center portion near each end of the meat (two thermocouples total per roast), i.e., the approximate geometric center of a steak to be subsequently sliced from each end of the roast.

Searing was conducted in a standard electric kitchen oven (model 96112, Kenmore, Hoffman States, IL) that was preheated to 260°C (500°F) and then set on "broil." Once the set temperature of the oven was attained, two intact or two nonintact subprimals, one for each target cooking temperature (37.8 and 48.9°C [100 and 120°F]), were placed in the searing oven for ca. 15 min and then transferred to an electric convection oven (model VC4ED, Vulcan-Wolf, Louisville, KY) that was preheated to 121.1°C (250°F). The meat was then cooked to internal temperatures of either 48.9 or 37.8°C; depending on the target cooking temperature, the cooking times typically ranged from ca. 75 to 145 min. Although the six restaurants surveyed routinely cooked roasts to internal temperatures of 48.9°C, we also cooked some roasts to an internal temperature of 37.8°C because some chefs stated that on occasion they cooked smaller roasts to this temperature. Following cooking, the meat was transferred to a warming oven (NFS, Ann Arbor, MI) that was preheated to 60.0°C (140°F) and held for up to 8 h; steaks were cut from each end of each roast at 2-h intervals.

Meat was sampled by slicing a ca. 2-cm-thick portion from each end of the roast for searing and cooking and throughout holding, as would be practiced in most restaurants. Each steak was weighed, and the internal temperature of each steak was recorded using a handheld digital thermometer (AccuTuff 340, Atkins Technical, Inc., Gainesville, FL). The temperature was determined by taking five independent readings from the meat (protein) components of the top, middle (two readings), and bottom portions of each steak and from the fat portion of each steak. After a slice (steak) was obtained, the remaining portion of each rib eye roast was returned to the warming oven and held at 60.0°C (140°F) for up to 8 h, with sampling every 2 h.

Microbial analyses. Meat samples were combined with 50 ml (core samples) or 200 ml (steak samples) of 0.1% peptone water (Difco, BD, Franklin Lakes, NJ), blended for ca. 30 s (Magic Bullet, Homeland Housewares, Los Angeles, CA), and transferred to sterile filter bags as described previously (*30*, *33*, *39*). Appropriate dilutions were spread plated in duplicate onto nonselective tryptic soy agar (TSA) medium (Difco, BD) to quantify populations of injured cells and onto selective xylose lysine deoxycholate (XLD) agar (Difco, BD) plus rifampin (100 μg/ml; Sigma) to select for the *Salmonella* strains contained in the cocktail used as an inoculum. After culture incubation for 24 h at 35°C (95°F), typical black colonies on XLD agar were counted as *Salmonella*.

Statistical analyses. A complete randomized split-plot design was used. Evaluation of searing, cooking, and warm holding was conducted in duplicate, and a set of two independent samples was obtained for each sampling interval. The microbial data were log transformed, and data were analyzed using the SAS software, version 9.2 (SAS Institute, Cary, NC). Significant differences were determined at $\alpha = 0.05$. All variables were analyzed using the PROC MIXED of SAS for analysis of variance, and least-squares means were separated ($P \leq 0.05$) by using the least significant differences test generated by the PDIFF option.

RESULTS AND DISCUSSION

Survey of restaurants for preparation of prime rib. All six restaurants surveyed followed similar steps for the preparation of prime rib: searing, cooking, and warm holding (Table 1). Variations in the preparation time and temperature schedules among the restaurants were mostly related to differences in equipment type, meat size, and personnel training. None of the six restaurants surveyed prepared prime rib as prescribed by the Food Code *(44)*, presumably because by so doing they would not be able to serve "rare" prime rib, which is preferred by many customers. According to our survey *(9)*, refrigerated rib eye roasts were hand rubbed with spices and seasoning and then placed in a preheated convection oven or in a rotisserie oven for searing at an oven temperature of 204 or 260°C (400 or 500°F), respectively, for a 15 to 45 min (Table 1). Searing seals the surface of the meat and retains the juices,

TABLE 1. *Time and temperature parameters for preparation of prime rib as practiced by six restaurants surveyed in a Midwestern city in the United States*[a]

Preparation step	Time (min) or temp (°C)	Restaurants: A	B	C	D	E	F
Searing	Oven set point temp	218	204	260 (rotisserie)	No searing	204	260 (rotisserie)
	Time	20	20–25	30–45	No searing	15–20	20–25
Cooking	Oven set point temp	107	121	121	121	132	135
	Time	169 ± 21.0	194 ± 28.3	162 ± 32.5	183 ± 69	174 ± 32.6	133 ± 18.6
	Meat end point temp	48.9	48.9	48.9	48.9	48.9	48.9
Holding	Oven set point temp	60	48.9	71.1	60	48.9	60
	Time	256 ± 43.4	355 ± 59.0	94 ± 56.0	141 ± 1.10	265 ± 21.0	147 ± 48.5
	Meat temp[b]	54.1 ± 3.14 (49–59)	50.8 ± 3.50 (46.5–58)	56.4 ± 4.01 (49–61)	56.3 ± 3.4 (49–61.5)	54.5 ± 5.48 (49–64.5)	50.8 ± 3.50 (48.5–53)
	Meat end point temp	49.5 ± 1.5	48.1 ± 2.1	56.7 ± 5.8	55.7 ± 4.5	54.6 ± 8.2	50.0 ± 2.6

[a] Data represent information collected on three separate visits (one roast per visit) to each of the six restaurants surveyed.
[b] Mean (range) of meat temperatures during holding for ca. 1.5 to 6 h at 48.9, 60.0, or 71.1°C.

which enhances the overall moistness of the meat. A minimal increase in the internal temperature of the meat (i.e., 1 to 12°C) from an initial temperature of ca. 4°C (40°F) was measured during the searing process (data not shown).

The set temperature of the oven and cooking time differed by restaurant, ranging from 107 to 135°C (225 to 275°F) during 2.5 to 3 h and ca. 2.2 to 3.2 h, respectively (Table 1). It was common for the chefs to stop the cooking process when the meat reached an internal temperature of 48.9°C (120°F) as determined using a dial stem food thermometer, which yielded a rare to very rare beef subprimal. Although uncommon, one of the restaurants cooked smaller rib eyes to an internal temperature of 37.8°C (100°F). These cooking processes are not in compliance with the Food Code *(44)* because they do not include a definitive holding time at a specified temperature (e.g., hold for 112 min at 54.4°C [130°F]). Although the USDA-FSIS requires meat processors to calibrate thermometers and other process measuring devices used at critical control points to meet the critical limits following a written protocol and at an adequate frequency, such requirements are not mandated by the U.S. Food Code. The cooked meat was transferred to a holding oven before being sliced and served to patrons. The set temperatures within the holding oven ranged from ca. 48.9 to 71°C (160°F) (Table 1), and changes in the appearance of the meat were minimal during this step (data not shown). Thereafter, when a customer requested a "well done" portion of prime rib, the chef typically removed the subprimal (which was originally cooked to a rare to very rare degree of doneness) from the holding oven, cut a steak of desired thickness, and subsequently immersed it in hot meat juice until the expected color for a well-done portion of prime rib was achieved. Holding times, which ranged from ca. 1.5 to 6.0 h (Table 1), were not related to the preparation of the prime rib but were associated with the meal planning for each restaurant. More specifically, prime rib is typically served for dinner, and restaurants start dinner preparations early in the morning, resulting in holding times of up to 11 h until the kitchen closes for the day. Any leftovers from the prime rib were either chilled "as is" and served the following day or were sliced, chilled, and served as a prime rib sandwich the next day.

Translocation of *Salmonella* during blade tenderization of rib eye roasts. Mechanical tenderization is primarily used to improve the eating quality of lower quality cuts of meat. Although the food service industry currently uses intact cuts of meat for the preparation of prime rib, the availability of tenderized subprimals and the desire to provide a more consistent eating quality for customers may prompt the industry to utilize nonintact beef products in the foreseeable future. For this reason, as one objective of the present study, we evaluated translocation and subsequent thermal inactivation of *Salmonella* within beef rib eye roasts that were blade tenderized. The National Cattlemen's Beef Association *(37)* reported that at least 18% of beef products available at retail in the United States are

TABLE 2. Salmonella *populations recovered from sequential segments of prime rib inoculated on the fat side and single-pass tenderized with the fat side facing up*[a]

Segment no.	*Salmonella* recovered (log CFU/g)[b]	Translocation (%)[c]
1	5.83 ± 0.28 A	93.7
2	3.53 ± 0.04 A	0.43
3	3.11 ± 0.07 BC	0.16
4	2.48 ± 0.01 CD	0.03
5	2.82 ± 0.63 D	0.13
6	3.60 ± 0.12 B	0.51
Total[d]	5.88 ± 0.27	94.94

[a] Initial mean ± SD population of *Salmonella* recovered from segment 1 of one nontenderized subprimal (control) was 5.90 ± 0.03 log CFU/g, $n = 12$ (six core samples from each of two trials).

[b] Values are the mean ± SD of six samples for each of the segments shown obtained from 6 cores from one tenderized subprimal in each of two trials (12 total cores). Means with different letters are significantly different ($P \leq 0.05$).

[c] Calculated as (CFU/g of tenderized subprimal core segment/CFU/g of segment 1 of nontenderized control subprimal core) × 100.

[d] Total *Salmonella* population transferred into all six segments of a core sample.

mechanically tenderized or injected with solutions for enhancement of tenderness and/or flavor.

In the present study, translocation of the pathogen into the interior of the tenderized muscle was observed after passage through the mechanical tenderizer. Most cells (93.7%) transferred into segment 1, the top-most 1 cm of the tenderized prime rib roast, and ca. 1.3% of the population of *Salmonella* inoculated onto the surface of the meat was subsequently recovered from segments 2 through 6 of the rib eye (Table 2). Differences in recovery of *Salmonella* were observed among segments 1 through 6 ($P \leq 0.05$). Populations of 3.11 and 2.48 log CFU/g of *Salmonella* were recovered from segments 3 and 4, respectively, the approximate geometric center of the prime rib; this level is equivalent to 0.19% of the population on the surface of the subprimal. Blade tenderization resulted in translocation of ca. 3.6 log CFU/g vertically to the bottom (i.e., segment 6) of the prime rib. In segments 5 and 6, an increase in percent recovery of *Salmonella* was observed compared with segment 4, presumably due to the vacuum created when the blades were retracted *(30, 31, 33)*.

As reported elsewhere, blade tenderization transfers 3 to 4% of surface contamination to the center of subprimals regardless of the initial population (ca. 0.5 to 5.5 log CFU/g) inoculated onto the surface *(30–33, 39, 41)*. Translocation can be affected by differences in the meat muscles used (e.g., inside round versus bottom round), blade tenderization equipment (e.g., automated Ross Tenderizer versus manual Jaccard tenderizer), and other factors. The translocation of microorganisms throughout the muscle after mechanical tenderization is owing to physical forces (e.g., blade insertion), which in turn can be affected by factors such as blade shape, muscle structure, product temperature, and fat content *(37)*. The intramuscular fat content of the rib eye can vary from 2 to 10% for slight to slightly abundant marbling *(17)*. Other investigators have also quantified translocation of *Salmonella* and STEC into meats as a consequence of blade tenderization, chemical injection, cubing, or vacuum tumbling *(1, 19, 21–23, 30, 31, 33, 37, 46)*. These studies have also revealed that translocation of the pathogen occurs throughout all layers of tenderized meat, with the majority of the cells residing within the top-most portion of the nonintact muscle *(30–33)*.

A gradual decrease in populations of *Salmonella* was observed from the surface of the rib eye to a point beyond the midpoint of the meat's thickness (segments 1 through 4), after which an increase was observed (segments 5 and 6). One explanation for this distribution is that the tips of the blades may be carrying bacteria that are pressed between the blade surface and the meat tissue as the blade cuts through the meat; these bacteria are not being deposited on the meat tissue but rather are being transported directly into the deeper tissues. Once the blade reverses direction and begins to pull away from the meat, some of these cells would be dislodged from the surface of the blade and become deposited near the bottom of the blade's traveling path. Another explanation is that juice from the inoculated surface (inoculated fat side) could migrate to the bottom of the subprimal, carrying bacteria with it. Thus, more meat juice and bacterial cells would be recovered from the bottom-most portions of the roast, i.e., segments 5 and 6.

Fate of *Salmonella* during preparation of intact prime rib. For roasts treated with process B, total reductions in *Salmonella* populations of ca. 1.3 and 4.6 log CFU/g were found on XLD agar plates following searing (15 min at 260°C [500°F]) and cooking (internal temperature of 48.9°C [120°F]), respectively, of intact (nontenderized) rib eye (Table 3). No appreciable difference was found in populations of the pathogen grown on TSA (for recovery of injured cells) and those grown on XLD agar among the four treatments (i.e., processes A through D) evaluated in this study (Table 3); therefore, no further results for *Salmonella* recovery on TSA are reported. For comparison, Goodfellow and Brown *(24)* reported reductions of ca. 2.6 log CFU/g for *Salmonella* in roast beef (2.27 kg [5 lb]) cooked to an internal temperature of 48.9°C in an oven set at 121.1°C (250°F). In the present study, subsequent holding of the cooked intact rib eye for 2 h in an oven set at 60.0°C (140°F) resulted in a slight increase (ca. 0.3 log CFU/g) in pathogen populations, but thereafter populations decreased about 0.9 to 1.1 log CFU/g after 4 to 8 h of holding compared with populations of the pathogen present after cooking (Table 3). There was also a noticeable decrease (ca. 4.5 to 13°C) in the temperature of the meat during holding of the cooked intact rib eye in the warming oven (Table 4). For process A, total reductions of ca. 1.3 and 4.7 log CFU/g were also observed following searing and cooking, respectively, of intact (nontenderized) rib eye to an internal temperature 37.8°C (100°F) (Table 3). Populations of

TABLE 3. Salmonella *recovery from samples collected during searing, cooking, and holding of intact and nonintact prime rib and cultured on nonselective (TSA) and selective (XLD) media*[a]

Preparation step	Mean ± SD *Salmonella* recovered (log CFU/g)[b]							
	TSA				XLD			
	Intact		Nonintact		Intact		Nonintact	
	Process A	Process B	Process C	Process D	Process A	Process B	Process C	Process D
Uncooked	6.21 ± 0.37 A		5.84 ± 0.24 AB		5.88 ± 0.62 A		5.58 ± 0.60 AB	
Searing	4.88 ± 0.44 BCD	4.93 ± 0.44 BCD	5.39 ± 0.21 ABC	5.07 ± 0.34 ABCD	4.56 ± 0.31 BCD	4.61 ± 0.50 BCD	5.26 ± 0.18 ABC	5.05 ± 0.36 ABC
Cooking	1.14 ± 0.33 GHIJ	1.28 ± 0.59 GHIJ	2.60 ± 0.90 E	1.58 ± 0.74 EFG	1.14 ± 0.33 EFGH	1.28 ± 0.59 EFG	2.14 ± 0.87 EF	1.65 ± 0.55 E
Holding								
2 h	1.58 ± 0.76 EFGH	1.57 ± 0.98 EFGH	4.25 ± 0.60 D	2.09 ± 0.54 EFG	1.59 ± 0.79 E	1.57 ± 0.98 EF	4.10 ± 0.54 CD	1.88 ± 0.79 E
4 h	1.20 ± 0.40 GHIJ	0.59 ± 0.39 J	4.23 ± 0.48 D	1.48 ± 1.03 EFGHI	1.05 ± 0.23 EFGH	0.47 ± 0.18 H	3.92 ± 0.43 D	1.44 ± 0.96 EFG
6 h	1.28 ± 0.39 GHIJ	0.66 ± 0.21 HIJ	4.36 ± 1.08 CD	1.82 ± 0.79 EFG	0.96 ± 0.34 EFGH	0.66 ± 0.21 FGJ	3.81 ± 1.24 D	1.60 ± 0.85 E
8 h	2.48 ± 1.14 EF	0.67 ± 0.28 IJ	4.20 ± 1.10 D	1.52 ± 0.47 EFGHI	1.89 ± 1.04 E	0.68 ± 0.27 GH	3.76 ± 0.74 D	1.35 ± 0.36 EFG

[a] TSA, tryptic soy agar; XLD, xylose lysine deoxycholate agar.
[b] Within each medium (TSA or XLD), means with different letters are significantly different ($P \leq 0.05$).

TABLE 4. *End point target temperatures after searing, cooking, and holding of inoculated intact (nontenderized) and nonintact (tenderized) rib eye roasts*

Preparation step	Mean ± SD temp (°C)			
	Intact		Nonintact	
	Process A	Process B	Process C	Process D
Searing[a]	17.1 ± 1.6	19.0 ± 2.9	13.7 ± 7.1	14.9 ± 6.8
Cooking[b]	49.7 ± 10.6	57.8 ± 10.5	45.8 ± 6.2	59.3 ± 9.4
Holding[c]				
2 h	47.6 ± 3.5	53.3 ± 3.5	46.1 ± 5.6	51.9 ± 4.3
4 h	47.6 ± 3.8	50.4 ± 2.0	45.9 ± 3.1	47.4 ± 2.1
6 h	45.8 ± 4.0	47.6 ± 2.0	45.6 ± 2.0	46.3 ± 2.1
8 h	43.7 ± 5.0	44.4 ± 2.8	45.3 ± 2.5	43.3 ± 3.3

[a] Temperature readings (taken at 5-s intervals during a 15-min searing treatment) recorded by one thermocouple from within each of two subprimals in each of two trials (720 total readings).
[b] Temperature readings (taken at 5-s intervals during ca. 75- to 145-min cooking treatments) recorded by two thermocouples from within each of two subprimals in each of two trials until the target temperature was achieved by both thermocouples within each subprimal (900 to 1,750 total readings).
[c] Temperature readings (taken at 5-s intervals during 2- to 8-h holding treatment) recorded by one thermocouple from within each of two subprimals in each of two trials (1,440 to 5,760 total readings).

Salmonella remained generally unchanged (<1.0 log CFU/g increase or decrease) after intact prime rib was cooked to the target temperature of 37.8°C and held for up to 8 h at 60.0°C. In addition, when pathogen numbers decreased to below the detection limit (0.40 log CFU/g), *Salmonella* was recovered by enrichment regardless of the time and temperature conditions used to prepare the prime rib (Table 5).

Restaurants are required to follow the Food Code *(44),* which specifies a final cooked temperature rather than prescribing a target reduction in pathogen populations. Our survey of six restaurants revealed that none of these establishments were in compliance with the Food Code because their cooking regimens did not include a required holding time at a specified temperature. Although we observed reductions of the pathogen to below the detection limit (≤0.40 log CFU/g) from an initial population of ca. 5.7 log CFU/g, viable cells were recovered during the extended warm holding period, indicating survival of a small population of the pathogen on or within nontenderized (intact) prime rib. Blankenship *(3)* recovered *Salmonella* from roast beef cooked to an internal temperature of 57.2°C (135°F) and, therefore, recommended cooking roast beef to an internal temperature of 62.8°C (145°F) uniformly throughout the roast to obtain a salmonellae-free product, especially in the presence of a high initial inoculum. Injection of steam either at the beginning or at the end of the cooking process to increase the relative humidity in the environment also contributed to the destruction of *Salmonella* in beef roasts *(3)*. In the present study, cooking whole

TABLE 5. *Recovery of* Salmonella *by direct plating and enrichment from intact (nontenderized; processes A and B) and nonintact (tenderized; processes C and D) rib eye roasts*

Process (target cooking temp)	Treatment	*Salmonella* recovery[a]	
		Direct plating[b]	Enrichment[c]
A (37.8°C)	Searing	4/4	0/0
	Cooking	1/4	2/3
	Holding		
	2 h	3/4	1/1
	4 h	2/4	2/2
	6 h	2/4	2/2
	8 h	3/4	1/1
B (48.9°C)	Searing	4/4	0/0
	Cooking	0/4	2/4
	Holding		
	2 h	1/4	3/3
	4 h	0/4	3/4
	6 h	0/4	4/4
	8 h	0/4	4/4
C (37.8°C)	Searing	4/4	0/0
	Cooking	4/4	0/0
	Holding		
	2 h	4/4	0/0
	4 h	4/4	0/0
	6 h	4/4	0/0
	8 h	4/4	0/0
D (48.9°C)	Searing	4/4	0/0
	Cooking	2/4	2/2
	Holding		
	2 h	4/4	0/0
	4 h	3/4	1/1
	6 h	4/4	0/0
	8 h	2/4	2/2

[a] Enrichment and direct plating results for a composite of top, middle, and bottom (summation of 2 steaks × 2 trials; 4 steaks per temperature) obtained from cooked steaks.
[b] Number of rib eye steaks from which *Salmonella* was recovered by direct plating/total number of composite samples direct plated.
[c] Number of rib eye steaks from which *Salmonella* was recovered by enrichment/number of steaks from which samples were enriched.

muscle, nontenderized prime rib to internal temperatures of 37.8 or 48.9°C (100 or 120°F) and then holding at 60.0°C for up to 8 h provided no appreciable lethality compared with searing and cooking alone.

Survival of *Salmonella* during preparation of nonintact prime rib. For roasts treated with process D, total reductions of 0.5 and 3.9 log CFU/g of *Salmonella* were achieved as a result of searing and cooking, respectively, of blade tenderized rib eye that was cooked to a target end point temperature of 48.9°C (120°F) (Table 3). With process C, slightly lower total reductions of 0.3 and 3.4 log CFU/g were achieved when blade tenderized rib eyes were seared and cooked, respectively, to a target end point temperature of 37.8°C (100°F). For roasts treated with process C, cells of the pathogen were recovered only via direct plating, whereas for those treated with process D when *Salmonella* populations decreased to below the limit of detection (0.40 log CFU/g), recovery was achieved by enrichment (Table 5). Johnston et al. *(26)* reported *Salmonella* survival in mechanically tenderized roasts cooked in an oven to an internal temperature of 54.4°C (130°F); survival was observed for both the surface and core samples, indicating that cooking nonintact beef to 54.4°C represents a potential public health concern. Marsden et al. *(36)* reported that cooking to an internal temperature of 43.3°C (110°F) or 48.9°C followed by a 1-h holding period at 48.9°C resulted in a considerable reduction in *Salmonella* (ca. 4.5-log decrease). In a later study of blade tenderized beef rounds, Marsden et al. *(35)* also reported that a 2.73-log reduction of *Salmonella* was achieved in mechanically tenderized steaks cooked to a target internal temperature of 48.9°C. Wendelburg et al. *(45)* reported *Salmonella* reductions of 4.54 and 4.80 log CFU/g during preparation of nonintact prime rib cooked to internal temperatures of 43.3 and 48.9°C, respectively, from an initial population of 5.75 log CFU/cm^2. The difference in destruction of *Salmonella* reported by Wendelburg et al. *(45)* and that found in the present study could be due to differences in the target internal cooking temperatures (43.3 and 48.9°C versus 37.8 and 48.9°C, respectively) and holding of the prime rib at room temperature before placement in the tempering oven. Differences in the *Salmonella* strains and the fat content of the subprimals could also impact pathogen survival, but considering the significant cooking time, the impact of such nonthermal factors is likely to be minimal.

For roasts treated with process D, subsequent holding of the cooked nonintact rib eye in an oven set at 60.0°C (140°F) for 2 h resulted in a slight increase (0.23 log CFU/g) in pathogen levels, but thereafter populations decreased ca. 0.05 to 0.3 log CFU/g after 4 to 8 h of holding compared with populations of the pathogen present after cooking (Table 3). For roasts treated with process C, holding cooked (to a target temperature of 37.8°C [100°F]) nonintact rib eye in a warming oven set at 60.0°C for 2 to 8 h resulted in increases in *Salmonella* populations of ca. 1.6 to 2.0 log CFU/g, respectively. Such increases during extended warm holding may pose a public health threat if nonintact rib eye were used for the preparation of prime rib and if appreciably high populations of *Salmonella* were present on or in raw product. The observed increase in *Salmonella* populations in the nonintact rib eye during holding in comparison with the minimal increases observed for intact rib eye was probably due to the internalization of the salmonellae within the deeper tissues of the meat, wherein the cells were likely protected from heat during cooking and the temperature was within the growth range for *Salmonella* during holding. Further research is warranted to fully elaborate the fate of *Salmonella* in both whole muscle and mechanically tenderized prime rib in response to various time and temperature conditions as detailed in the Food Code.

Effect of heating conditions on viability of *Salmonella* in prime rib. We validated the lethality of a method for preparing prime rib that is currently being practiced by

several restaurants in at least one major Midwestern city. Depending on the cooking temperature, processes A through D as detailed herein delivered ca. 3.4- to 4.7-log reductions in pathogen levels. Regardless of the process used to prepare prime rib, during searing at 260°C (500°F) for 15 min and cooking to a target internal temperature of 37.8 or 48.9°C (100 or 120°F), the mean internal temperature at the geometric center of rib eyes ranged from 13.7 to 19.0°C (57 to 66°F) and 45.8 to 57.8°C (115 to 136°F), respectively. During holding at 60.0°C (140°F) for up to 8 h, the mean internal temperature at the geometric center of the rib eye ranged from 43.3 to 53.3°C (110 to 128°F) (Table 4). In addition to measuring the internal temperature of the meat by inserting a thermocouple into the center portion of each end of a subprimal, a handheld thermometer was used to record five individual temperature readings at each sampling interval from each steak after it was cut from the end of each subprimal upon removal from the oven. The data collected using the handheld thermometer revealed that the average internal temperature within the steaks after searing was 28.2 ± 5.6°C (83 ± 10°F), whereas after cooking to 37.8 or 48.9°C, the average internal temperature within the steaks were 58.6 ± 4.8°C (137 ± 9°F) and 66.7 ± 4.1°C (152 ± 7°F), respectively (data not shown). Regardless of the cooking temperature achieved, during holding for 2 to 8 h at 60.0°C, the average internal temperature within the steaks was 41.2 ± 2.2°C (106 ± 4°F) (range, 36.1 to 45.6°C [97 to 114°F]; data not shown). These data may explain, at least in part, why minimal reductions of *Salmonella* were observed after searing and why cells of the pathogen were also recovered after cooking and holding. *Salmonella* can survive and perhaps even grow within the range of temperatures recorded in some of the steaks after removal from the oven.

In the present study, searing of intact prime rib for ca. 15 min in a kitchen oven maintained at 260°C (500°F) followed by cooking to either 37.8 or 48.9°C (100 or 120°F) reduced *Salmonella* populations by ca. 4.7 log CFU/g. These same processing variables applied to mechanically tenderized prime rib achieved reductions of ca. 3.7 log CFU/g. A companion study was conducted using the same methods as those detailed in the present study except that the prime rib was inoculated with a five-strain rifampin-resistant cocktail of STEC and after searing the prime rib was cooked to target internal temperatures of 37.8, 48.9, 60.0 (140°F), or 71.1°C (160°F). A 5-log reduction of STEC was achieved by searing and then cooking to an internal temperature of 71.1°C and holding at 60.0°C for at least 4 h and by searing and then cooking to 48.9 or 60.0°C and holding at 60.0°C for 8 h. A ca. 3.5-log reduction was achieved by searing and then cooking to 37.8°C and holding for 8 h at 60.0°C.

Regardless of the type of meat and the thermal processes applied, holding mechanically tenderized prime rib at 60.0°C (140°F) following cooking to 37.8°C (100°F) allowed for appreciable outgrowth of surviving *Salmonella* cells. Although this increase (ca. 2.0 log CFU/g) in pathogen levels is relatively low, it could make the finished product unsafe for consumption if relatively high populations of *Salmonella* were present on the raw product. Contamination of carcasses can occur during slaughter operations, with the majority of the contaminants (such as *Salmonella*) residing on the surface *(2, 6–8)*. Although trimming of carcasses can appreciably remove surface contamination, this process may also translocate organisms from the carcass surface to the newly exposed cut surfaces; however, the populations of *Salmonella* on this newly exposed surface (such as a rib eye) would likely be lower than the corresponding populations on the carcass or any meat cuts fabricated from it. Regardless of the pathogen populations on the surface of the rib eye, inadequate cooking or handling of the rib eye (and hence the prime rib steak) can have severe consequences and potentially cause foodborne illness, considering the relatively low infectious dose of some pathogens for sensitive populations. The infectious dose for nontyphoidal salmonellae can vary with serotype and the mode of infection; however, ingestion of $\leq$1,000 cells has caused human illness in more than half of 11 foodborne salmonellosis outbreaks analyzed *(5)*. For all of the reasons elaborated herein, use of mechanically tenderized rib eye may increase the potential risk of *Salmonella* survival during the processes of searing and cooking and result in subsequent pathogen population increases during extended warm holding as observed herein when roasts were cooked to 37.8°C and then held for up to 8 h at 60.0°C. These data highlight the importance of following established guidelines, notably the Food Code, for preparing prime rib and underscore the need and urgency for better education of consumers regarding the potential risks associated with ordering and consuming (rare) prime rib.

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