Fate of *Escherichia coli* O157:H7 in Mechanically Tenderized Beef Prime Rib following Searing, Cooking, and Holding under Commercial Conditions†

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ABSTRACT

We evaluated the effect of commercial times and temperatures for searing, cooking, and holding on the destruction of *Escherichia coli* O157:H7 (ECOH) within mechanically tenderized prime rib. Boneless beef ribeye was inoculated on the fat side with ca. 5.7 log CFU/g of a five-strain cocktail of ECOH and then passed once through a mechanical tenderizer with the fat side facing upward. The inoculated and tenderized prime rib was seared by broiling at 260°C for 15 min in a conventional oven and then cooked in a commercial convection oven at 121.1°C to internal temperatures of 37.8, 48.9, 60.0, and 71.1°C before being placed in a commercial holding oven maintained at 60.0°C for up to 8 h. After searing, ECOH levels decreased by ca. 1.0 log CFU/g. Following cooking to internal temperatures of 37.8 to 71.1°C, pathogen levels decreased by an additional ca. 2.7 to 4.0 log CFU/g. After cooking to 37.8, 48.9, or 60.0°C and then warm holding at 60.0°C for 2 h, pathogen levels increased by ca. 0.2 to 0.7 log CFU/g. However, for prime rib cooked to 37.8°C, pathogen levels remained relatively unchanged over the next 6 h of warm holding, whereas for those cooked to 48.9 or 60.0°C pathogen levels decreased by ca. 0.3 to 0.7 log CFU/g over the next 6 h of warm holding. In contrast, after cooking prime rib to 71.1°C and holding for up to 8 h at 60.0°C, ECOH levels decreased by an additional ca. 0.5 log CFU/g. Our results demonstrated that to achieve a 5.0-log reduction of ECOH in blade tenderized prime rib, it would be necessary to sear at 260°C for 15 min, cook prime rib to internal temperatures of 48.9, 60.0, or 71.1°C, and then hold at 60.0°C for at least 8 h.

Commonly referred to by consumers as “prime rib,” beef ribeye is one of the most preferred cuts of beef because of its tenderness, flavor, and juiciness. In addition to marbling, the method by which prime rib is prepared can also appreciably accentuate its rich flavor and enhance its desired textural attributes. More specifically, prime rib is typically seared for a short time (i.e., 15 to 40 min) at a high temperature (i.e., 204 to 260°C) to retain the juices and flavor of the meat, and then it is cooked at lower temperatures (i.e., 121.1°C) to rare (i.e., 48.9°C or medium rare (i.e., 57.2°C) doneness as preferred by most consumers (6). In food service and/or restaurant settings, after the searing and cooking steps, the prime rib may be held at low temperatures for an extended period, such as 1 to 11 h (6), and then served according to the consumers preference or specification. Although most prime rib is prepared from intact subprimal cuts of meat, it is not uncommon for beef ribeye to be mechanically tenderized prior to cooking, particularly if a lower grade of meat is used.

As for any type of raw beef, the primary pathogen of concern for prime rib would be Shiga toxin–producing *Escherichia coli* (STEC) (4, 18). It is noteworthy that over the last decade, beef that has been mechanically tenderized or chemically enhanced, that being nonintact beef, has been incriminated as a vehicle for transmission of *E. coli* O157:H7 (ECOH) (3, 4, 7, 8). As reported by the U.S. Department of Agriculture, Food Safety and Inspection Service (USDA-FSIS), since the early 2000s there have been at least five outbreaks associated with this pathogen involving nonintact meat products (7, 8, 23), and approximately 1.7 million pounds (7.7 million kilograms) of mechanically tenderized and/or chemically enhanced beef have been recalled due to potential contamination with ECOH (26). At present, the USDA-FSIS considers ECOH and six non-O157:H7 serotypes of STEC, those being O26, O45, O103, O111, O121, and/or O145 strains, as adulterants in both raw ground and whole muscle cuts that have been subjected to enhancement processes such as tenderization, restructuring, cubing, and/or vacuum tumbling (22–25).

Given the epidemiologic evidence that ECOH outbreaks have been linked to consumption of undercooked
nonintact beef, numerous studies have been conducted to address the translocation of ECOH and STEC into beef subprimals following tenderization and/or enhancement and to evaluate the effectiveness of commercial cooking parameters and/or processes to destroy both of these pathogens in nonintact beef \(9, 10, 13, 14, 29\). These researchers reported that enhancement processes, such as mechanical tenderization, chemical injection, cubing, restructuring, and/or vacuum tumbling, transfer microorganisms, such as ECOH and STEC, from the surface into the deeper tissues of the meat wherein they may be more resistant to subsequent thermal challenge, thus increasing the public health risk associated with nonintact meat. There is also a potential food safety concern created by the commercial practice of low-temperature, long-time heating when preparing prime rib roast that may be amplified when cells of STEC are present and when the meat is mechanically tenderized or chemically enhanced. To address these concerns, we evaluated standard commercial practices for searing, cooking, and holding nonintact beef prime rib and the resulting effect on the destruction of ECOH.

MATERIALS AND METHODS

**Bacterial strains.** Approximately equal numbers of each of the following five rifampin-resistant \(100 \mu\text{g/ml;}\) Sigma Chemical Company, St. Louis, MO) strains of ECOH, (i) USDA-FSIS 011-82, (ii) ATCC 43888, (iii) ATCC 43889, (iv) ATCC 43890, and (v) USDA-FSIS 45756, were maintained and subsequently prepared as a cocktail for this study as described by Luchansky et al. \(14\).

**Inoculation and tenderization of subprimals.** Vacuum-packaged boneless beef lip-on ribeye (USDA Institutional Meat Purchase Specifications no. 112A, ca. 8 to 9 kg [18 to 20 lb] each) were purchased from a local commercial wholesale distributor and stored at 4°C for up to 3 days before being inoculated (ca. 5.7 log CFU/g) as described \(15, 16\). Next, with the inoculated side (the fat side) facing upward, the subprimals were passed longitudinally through the tenderizer (TC700M, Ross Industries, Inc., Midland, VA). Inoculated prime rib that was not mechanically tenderized served as positive controls. Following tenderization, a total of up to six core samples were obtained from one prime rib and cut into five or six consecutive segments as previously described \(13, 14\). A total of four trials were conducted, with a single trial consisting of five tenderized prime ribs and one positive control (nontenderized prime rib). The translocation matrix, data for one inoculation level, six core samples, six segments per core, and four trials were collected for a total of 144 core samples tested.

**Processing of mechanically tenderized prime rib.** Mechanically tenderized boneless beef lip-on ribeye inoculated with ECOH (ca. 5.7 log CFU/g) were seared with the inoculated/tenderized fat side facing upward for 15 min at 260°C (500°F) on the top shelf of a preheated electric range (model 96112, Kenmore, Hoffman States, IL) set at “broil.” After searing, one steak (ca. 3.8 cm in thickness; Fig. 1A) was separately cut from both ends of the prime rib and placed on polystyrene foam packaging trays (Koch Supplies, Kansas City, MO). The remaining portion of the prime rib was transferred to a preheated electric convection oven (Fig. 1B) (model VC4ED, Vulcan-Wolf, Louisville, KY). Prime rib was then cooked at 121.1°C (250°F) to instantaneous internal endpoint temperatures of 37.8°C (100°F; process A), 48.9°C (120°F; process B), 60.0°C (140°F; process C), or 71.1°C (160°F; process D). Two calibrated stainless steel thermocouple probes (type J, model HQ4Q1N-116-18, Omega Engineering, Inc., Stamford, CT) were inserted into the central portion of each end of the prime rib to a depth of ca. 6.5 cm and used to measure the internal temperature of the meat during searing and cooking. When both thermocouples within a prime rib achieved the desired target internal endpoint temperature during cooking, the prime rib was removed from the convection oven, and then one steak (ca. 3.8 cm in thickness) was separately cut from both ends of the prime rib, and the remaining portion of the prime rib was placed in a warming oven (NFS, Ann Harbor, MI) and held at 60.0°C (Fig. 1C). Briefly,
at each 2-h interval for up to 8 h and for each target internal cooking
temperature, a prime rib was removed from the warming oven. Next,
one steak (ca. 3.8 cm in thickness) was separately cut from both ends
of the prime rib and placed on polystyrene foam packaging trays; the
remaining portion of the prime rib was returned to the warming oven
for subsequent sampling. Following slicing, five temperature readings were taken from the meat or protein portions at the top,
middle high, middle low, and bottom sections of each steak and from
the fat portion at the top section of each steak with a calibrated
handheld digital thermometer (model AccuTuff 340, Atkins
Technical Inc., Gainesville, FL). Also, the temperature of the meat
and the temperature of the ambient air inside the ovens during
searing, cooking, and holding were continuously monitored with an
eight-channel thermocouple data logger (model OM-CP-OCT-TEMP, Omega Engineering) at 5- to 10-s intervals. For each of theour trials, seared samples were obtained for one inoculation
level, one searing temperature, four cooking processes, two steaks
per cooking process, and four trials, for a total of 32 steaks sampled from a seared prime rib. Cooked and held samples were obtained for
cooking temperatures, one holding temperature, four holding
times, two steaks per treatment, and four trials, for a total of 128
steaks samples from cooked and warmed prime rib. Control samples, i.e., uncooked but inoculated and tenderized prime rib, were obtained
for one inoculation level, four cooking treatments, four steaks per
cooking treatment, and four trials, for a total of 64 uncooked steaks.

Microbiological analyses. For enumeration of ECOH, cells of
the pathogen were recovered from cooked or uncooked

tenderized prime rib by slicing one steak from each end of each
side of the ribeye at each sampling interval. Next, each steak was
partitioned into three sections, top, middle, and bottom, which were
separately weighed and then subsequently macerated for ca. 45 s in
200 ml of 0.1% of sterile peptone water (BD, Franklin Lakes, NJ)
in a blender (Magic Bullet, Homeland Housewares, available at:
www.healthandfitnessproducts.com). The resulting fluid was

transferred into sterile filtered stomacher bags (type XX-C003,
Microbiology International, Frederick, MD) and then plated, with
and without prior dilution in sterile 0.1% peptone water, onto

sorbitol MacConkey (BD) plus rifampin (100 μg/ml; Sigma
Chemical Company) agar plates. Plates were incubated at 37°C
for 24 h, and sorbitol-negative colonies were enumerated as

ECOH. When pathogen levels decreased below the detection limit
(ranged from ≤0.60 to ≤1.08 log CFU/g) by direct plating,
samples were enriched as previously described (13, 14). Each of the
224 steaks sampled were portioned into three sections, for a
total of 672 pieces of meat sampled for all four trials.

Statistical analyses. Transfer of ECOH cells into the deeper
tissues of beef ribeye subprimals via mechanical tenderization was
expressed (as a percentage) as the average of the number of cells
(CFU per gram) recovered separately from each of the six

segments obtained from tenderized ribeye cores divided separately
by the average of the number of cells (CFU per gram) recovered from
segment 1 of the cores obtained from the nontenderized positive

control prime rib; this value was then multiplied by 100. The
standard deviations for the levels of the pathogen recovered from
each of the six segments and the cumulative totals recovered from
core samples were calculated using the statistical function option
that is provided with Excel 2003 software (Microsoft, Redmond,
WA). For the thermal inactivation phase of this study, the SAS
system (version 9.2, SAS Institute, Cary, NC) was used on the log

CFU per gram data to determine statistically significant (P ≤ 0.05)
differences in pathogen survival among searing, cooking, and

holding processes. Average log CFU per gram and their standard
deviations were calculated from individual sets of data for each of
the four separate trials and each of the thermal processes evaluated
using duplicate samples and/or steaks at each time interval. An
analysis of variance was used to determine differences in pathogen
reduction (log CFU per gram) observed for steaks exposed to
searing, cooking, or holding times, and significance was deter-

mined using the least significant difference technique at the P ≤ 0.05
significance level.

RESULTS

Translocation of ECOH into prime rib via mechanical
tenderization. As expected, there was a significant

linear decrease (P ≤ 0.05) in ECOH levels from the top

surface, i.e., the inoculated and tenderized side of the beef

ribeye, into the deeper tissues of the meat (Table 1). More

specifically, most of the ECOH cells were recovered from

segment 1 (17.23%), whereas the remaining ECOH cells were

recovered from segments 2 to 6 (total of 3.67%). The

remaining cells most likely remained on the tenderizer needles,
on the other parts of the machine such as the conveyor belt, in

the meat purge in the package wherein the meat was

inoculated, or on the filter bag when the meat was sampled

(13, 14). Also, more cells were recovered from segment 6 than

from segments 4 and 5, and this could be a consequence of the

suction and/or vacuum created by the withdrawal of blades
during the process of mechanical tenderization (13).

Come-up time and internal meat and oven temper-

atures during searing, cooking, and holding of tender-
ized prime rib. The average internal temperature of the

tenderized beef ribeye before searing was 6.7 ± 1.3°C.

<table>
<thead>
<tr>
<th>Segment no.</th>
<th>Initial level</th>
<th>% transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.63 ± 1.05 a</td>
<td>17.23</td>
</tr>
<tr>
<td>2</td>
<td>4.07 ± 0.79 c</td>
<td>0.38</td>
</tr>
<tr>
<td>3</td>
<td>4.67 ± 0.92 c</td>
<td>1.51</td>
</tr>
<tr>
<td>4</td>
<td>2.87 ± 0.56 b</td>
<td>0.02</td>
</tr>
<tr>
<td>5</td>
<td>4.33 ± 0.99 c</td>
<td>0.71</td>
</tr>
<tr>
<td>6</td>
<td>4.51 ± 0.73 c</td>
<td>1.05</td>
</tr>
<tr>
<td>Total</td>
<td>5.80 ± 0.17</td>
<td>20.90</td>
</tr>
</tbody>
</table>

*Means with different letters within columns are significantly
(P ≤ 0.05) different.

*Numbers are the average of six cores (segment 1 only) from one
nontenderized ribeye from each of four trials (24 total cores).

*Numbers are the average of 24 samples for each segment
obtained from six cores from one tenderized ribeye from each of
four trials (24 total cores) calculated as follows: (CFU per gram
of tenderized ribeye core segment/CFU per gram of segment 1 of
nontenderized control ribeye core) × 100.

*Total level of E. coli O157:H7 (log CFU per gram) transferred
into all six segments of a core sample.
During searing, the average temperature of the air inside the electric range was 157.3 ± 22.5°C. This temperature is the average of 1,010 total temperature measurements taken during searing for 15 min at 260°C in an electric range, for all four trials. After searing, the average internal temperature of the meat was 26.2 ± 13.6°C. The average come-up time during cooking to achieve the target instantaneous internal temperatures of 37.8, 48.9, 60.0, or 71.1°C were ca. 45.8 ± 39.2, 76.2 ± 39, 135.5 ± 52.1, and 190.8 ± 43.7 min, respectively. After cooking, the average internal temperature of prime rib roasts cooked to target instantaneous internal temperatures of 37.8, 48.9, 60.0, or 71.1°C were 41.9 ± 4.5, 51.3 ± 3.3, 61.7 ± 1.4, and 73.0 ± 1.8°C, respectively. These temperatures represent a total of 18,041 temperature measurements for four trials for all cooking temperature regimens tested (N = 4 trials, n = 4 cooking temperature regimens of 37.8, 48.9, 60.0, or 71.1°C). The average temperature of the air inside the electric convection oven during cooking was 125.1 ± 2.4°C. This temperature is the average of 4,251 total temperature measurements throughout cooking for all cooking temperatures tested (N = 4 trials, n = 4 cooking temperature regimens). The average internal temperature of tenderized prime rib pieces that were cooked to 37.8, 48.9, 60.0, or 71.1°C and then held for 8 h at 60.0°C were 46.0 ± 1.4, 47.6 ± 1.2, 50.3 ± 2.1, and 53.6 ± 1.0°C, respectively. These temperatures represent each target cooking temperature followed by holding at 60.0°C for up to 8 h for all four trials for each of two probes used in each trial. During holding, the average temperature of the air inside the warming oven was 55.9 ± 0.4°C.

Thermal inactivation of ECOH in nonintact prime rib. As expected, inactivation of ECOH cells was greater (P ≤ 0.05) after cooking tenderized prime rib at 121°C to instantaneous internal endpoint temperatures of 37.8, 48.9, 60.0, or 71.1°C in a convection oven and subsequent holding in a warming oven at 60.0°C for up to 8 h than after searing alone for 15 min at 260°C in an electric range. Also, the higher the internal endpoint cooking temperature, the greater the lethality towards ECOH compared with lower endpoint cooking temperatures (Fig. 2). In general, as expected, because the majority of the cells remained in the top-most 1 cm following mechanical tenderization, when prime rib steaks were portioned into top, middle, and bottom strips, the top strips after searing had appreciably more cells than did the middle and bottom strips (data not shown). However, after cooking prime rib to internal temperatures of 37.8 to 71.1°C and holding at 60.0°C for 2 to 8 h, no appreciable (P ≥ 0.05) differences were observed in the extent of thermal inactivation of ECOH that were transferred via tenderization between top, middle, and bottom strips (data not shown).

Statistical differences (P ≤ 0.05) in the extent of thermal inactivation of ECOH were observed when prime rib roasts were cooked to 37.8°C compared with 60.0°C and 71.1°C, but not with 48.9°C. However, for a given internal endpoint cooking temperature, there were no significant (P ≥ 0.05) differences in lethality of ECOH following holding at 60.0°C for 2, 4, 6, or 8 h. During holding at 60.0°C for 2 h, statistically significant differences (P ≤ 0.05) in the extent of thermal inactivation of ECOH were observed for prime rib pieces that were cooked to a target internal temperature of 37.8°C when compared with those cooked to 60.0 and 71.1°C, but not 48.9°C. Statistical differences were also observed after 2 h of holding for prime rib pieces that were cooked to a target internal temperature of 48.9°C when compared with those cooked to 71.1°C, but not with those cooked to 60.0°C. Likewise, when prime rib pieces were held for 4, 6, or 8 h at 60.0°C, significant (P ≤ 0.05) differences in lethality towards ECOH were observed for prime rib pieces cooked to target endpoint temperatures of 37.8°C compared with those cooked to a target endpoint temperature of 48.9, 60.0, or 71.1°C.

Results showed that searing boneless prime rib for 15 min at 260°C in an electric range resulted in a 1.1-log decrease in the level of ECOH. Following searing, when prime rib was cooked at 121°C to instantaneous internal
To date, however, there are no E. coli (1, 14, 20, 21). Of beef products sold at retail are 40\% following mechan-
ical and/or chemical tenderization of meat (9, 13, 14, 21). It has also been proposed that, in addition to safe handing and cooking instructions, tender-
ized meat must be labeled as such. Hence, consumers would be fully cognizant that they are purchasing or serving nonintact meat and should take the necessary precautions.

### DISCUSSION

Mechanical tenderization is a common and highly effective process used mostly by the beef industry, particularly in the food service and restaurant sectors, to enhance the quality of lower value cuts of beef (19). Among the various cuts of beef mechanically tenderized by the food service industry, 33\% are beef ribeye (2). It has also been estimated that about 18\% of beef products sold at retail are mechanically tenderized and/or chemically enhanced (2) and that about 50 million pounds (22.7 million kilograms) of mechanically tenderized meat are produced monthly in the United States (5). To date, however, there are no requirements by U.S. regulatory agencies for such products to be labeled as nonintact meat (2). From a public health perspective, there is considerable concern about consumers preferring or ordering steaks, as well as burgers for that matter, and restaurants and food service establishments preparing or serving meats that have been cooked to a rare (i.e., 54.4 to 57.2°C) or to a medium (i.e., 60.0 to 62.8°C) degree of doneness (1, 14, 20, 21). The threat of foodborne illness is further exacerbated by the misconception of consumers, restaurants, and food service establishments that nonintact cuts of beef are whole muscle cuts, and as a result such products may not be cooked to a sufficient temperature and/or for a sufficient time. Thus, the temperature achieved in the interior of the meat may not be sufficient to lessen consumer exposure to any ECOH cells that may be present in the center of the meat due to tenderization or enhancement given the low infectious dose of the pathogen. Therefore, the USDA-FSIS (25) has proposed that, in addition to safe handling and cooking instructions, tender-
ized meat must be labeled as such. Hence, consumers would be fully cognizant that they are purchasing or serving nonintact meat and should take the necessary precautions.

### TABLE 2. E. coli O157:H7 recovery by direct plating and enrichment from cooked rib portions

<table>
<thead>
<tr>
<th>Process (target cooking temp., °C)</th>
<th>Treatment</th>
<th>Direct plating(^a)</th>
<th>Enrichment(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A (37.8)</strong></td>
<td>Searing</td>
<td>24/24</td>
<td>0/0</td>
</tr>
<tr>
<td></td>
<td>Cooking</td>
<td>19/24</td>
<td>2/5</td>
</tr>
<tr>
<td>Holding for:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 h</td>
<td>20/24</td>
<td>4/4</td>
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</tr>
<tr>
<td>4 h</td>
<td>19/24</td>
<td>3/5</td>
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<tr>
<td>6 h</td>
<td>21/24</td>
<td>1/3</td>
<td></td>
</tr>
<tr>
<td>8 h</td>
<td>16/24</td>
<td>8/8</td>
<td></td>
</tr>
<tr>
<td><strong>B (48.9)</strong></td>
<td>Searing</td>
<td>24/24</td>
<td>0/0</td>
</tr>
<tr>
<td></td>
<td>Cooking</td>
<td>3/24</td>
<td>4/21</td>
</tr>
<tr>
<td>Holding for:</td>
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<td></td>
<td></td>
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<tr>
<td>2 h</td>
<td>7/24</td>
<td>8/17</td>
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<tr>
<td>4 h</td>
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<td>6 h</td>
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<tr>
<td>8 h</td>
<td>1/24</td>
<td>3/23</td>
<td></td>
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<tr>
<td><strong>C (60.0)</strong></td>
<td>Searing</td>
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<td>0/21</td>
</tr>
<tr>
<td>Holding for:</td>
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<td></td>
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<tr>
<td>2 h</td>
<td>7/24</td>
<td>1/17</td>
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<tr>
<td>4 h</td>
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<tr>
<td>8 h</td>
<td>4/24</td>
<td>0/20</td>
<td></td>
</tr>
<tr>
<td><strong>D (71.1)</strong></td>
<td>Searing</td>
<td>24/24</td>
<td>0/0</td>
</tr>
<tr>
<td></td>
<td>Cooking</td>
<td>3/24</td>
<td>0/21</td>
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<tr>
<td>Holding for:</td>
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<tr>
<td>2 h</td>
<td>2/24</td>
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<td>8 h</td>
<td>0/24</td>
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\(^a\) Enrichment and direct plating results for a composite of top, middle, and bottom portions (2 steaks × 3 portions × 4 trials = 24 strips total per each temperature) obtained from cooked steaks.

\(^b\) Recovery of E. coli O157:H7 by direct plating from total composite samples that were direct plated.

\(^c\) Recovery of E. coli O157:H7 by enrichment from total composite samples that were enriched.

Several studies have addressed and/or quantified internalization of STEC and Salmonella following mechanical and/or chemical tenderization of meat (9, 13, 14, 21). Herein, we also validated that cells of ECOH inoculated on the surface of beef ribeyes were transferred into the deeper tissues following mechanical tenderization. Our results compare favorably with the results of other studies, in that mechanical tenderization and/or chemical enhancement transferred cells of STEC throughout the interior of beef subprimals, with the majority of the cells remaining in the outermost layer of the meat (11–14, 16, 29). Therefore, despite the low prevalence (<0.083 to 2.0\%) and the relatively low levels (<0.375 CFU/cm\(^2\)) of this pathogen present on the surface of whole muscle meats (3, 12), the use of low-temperature and long-time cooking regimens practiced by food service personnel, restaurants, and consumers to prepare nonintact prime rib may present a serious public health risk if a minimum lethal cooking
temperature is not attained and/or maintained during cooking. Such a scenario emphasizes the need for more research to develop and validate proper time and temperature preparation conditions to better manage food safety concerns related to thermal inactivation of ECOH associated with nonintact prime rib roasts.

Numerous studies have reported on thermal inactivation of STEC in tenderized and/or enhanced steaks cooked on different appliances using various time-temperature regimens (13–15, 17, 29). However, to the best of our knowledge, there are no published data on the effectiveness of commercial practices, i.e., low-temperature cooking and long-time heating, on the survival of ECOH in mechanically tenderized prime rib. There have been a few articles detailing the viability of Salmonella in beef roasts (6, 19, 21, 28). Snyder et al. (19) reported that when boneless prime rib was cooked in a controlled-vapor oven for 6 h at 54.4°C, Salmonella levels decreased by ca. 5.8 log CFU/g. In addition, the authors reported that postcook holding for 28 h at 55.0°C resulted in 7.7-log and 8.2-log decreases in Salmonella in the geometric center and on the surface of the beef rib roasts, respectively. As another example, Wendelburg et al. (28) reported that cooking tenderized beef ribeye roasts to target internal temperatures of 43.3 or 48.9°C in a conventional kitchen oven at 190.6°C resulted in a 4.5- and 4.8-log reduction in Salmonella, respectively. Moreover, when ribeyes were tempered for up to 1 h at room temperature and then held in a holding oven at 48.9°C (120°F) for up to 2 h, Salmonella levels decreased by 4.5 to 5.3 log CFU/g. Likewise, Calle (6) reported a ca. 3.2- and 4.6-log reduction in Salmonella levels in mechanically tenderized prime rib roasts that were seared at 260°C for 15 min and then cooked to target internal temperatures of 37.8 and 48.9°C, respectively, in a convection oven maintained at 121°C. However, this same author reported that when prime rib roasts were held at 60.0°C for 2 h after being cooked to target internal temperatures of 37.8 and 48.9°C, pathogen levels increased by ca. 1.8 and 0.4 log CFU/g, respectively, and then remained relatively unchanged for up to 8 h of holding at 60.0°C. These data for Salmonella are in general agreement with our data for ECOH, given that searing mechanically tenderized prime rib for 15 min at 260°C and cooking at 121°C to target instantaneous internal endpoint temperatures of 48.9 to 71.1°C reduced ECOH levels by ca. 4.8 to 5.2 log CFU/g and did not allow for multiplication of the pathogen after holding the product at 60.0°C for 4 to 8 h. Our data also revealed that, regardless of the cooking temperature tested, when five individual temperature readings were measured from each prime rib steak after removal from the warming oven, the average internal temperature in the prime rib steak during holding for 2 to 8 h at 60.0°C ranged from 39.6 to 48.6°C (Table 3). Therefore, it may be necessary to evaluate combinations of searing and cooking temperatures in combination with a defined holding time to achieve a 5.0-log reduction of ECOH in mechanically tenderized prime rib. Our data demonstrated that cooking nonintact prime rib roasts to instantaneous internal temperatures of ≥48.9°C and holding at 60.0°C for 4 to 8 h would be effective for controlling the subsequent outgrowth of ECOH in prime rib roasts during the typical period of extended warm holding.

### Table 3. Average temperature and range of temperatures (endpoint target temperatures) after searing, cooking, and holding inoculated and tenderized prime rib roasts

<table>
<thead>
<tr>
<th>Process (target cooking temp, °C)</th>
<th>Searing (°C)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Cooking (°C)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Time (h)</th>
<th>Temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (37.8)</td>
<td>40.4 (23.3–65.6)</td>
<td>61.0 (52.8–71.1)</td>
<td>2</td>
<td>46.0 (39.4–51.7)</td>
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<td></td>
<td></td>
<td></td>
<td>4</td>
<td>45.2 (41.1–49.4)</td>
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<td></td>
<td></td>
<td></td>
<td>6</td>
<td>43.4 (40.6–48.3)</td>
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<td></td>
<td></td>
<td></td>
<td>8</td>
<td>41.3 (35.6–46.1)</td>
</tr>
<tr>
<td>B (48.9)</td>
<td>40.4 (23.3–65.6)</td>
<td>62.6 (55.0–78.9)</td>
<td>2</td>
<td>45.2 (41.1–51.1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>43.9 (38.9–48.3)</td>
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<td></td>
<td>6</td>
<td>41.6 (33.3–46.1)</td>
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<td></td>
<td></td>
<td></td>
<td>8</td>
<td>39.6 (33.9–48.3)</td>
</tr>
<tr>
<td>C (60.0)</td>
<td>40.4 (23.3–65.6)</td>
<td>69.6 (62.2–82.2)</td>
<td>2</td>
<td>46.4 (41.5–52.8)</td>
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<td></td>
<td>4</td>
<td>42.7 (33.9–48.3)</td>
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<td></td>
<td></td>
<td></td>
<td>6</td>
<td>42.3 (41.1–51.1)</td>
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<td></td>
<td>8</td>
<td>41.9 (37.8–46.1)</td>
</tr>
<tr>
<td>D (71.1)</td>
<td>40.4 (23.3–65.6)</td>
<td>79.0 (67.8–87.8)</td>
<td>2</td>
<td>48.6 (42.8–55.0)</td>
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<td></td>
<td>4</td>
<td>45.6 (40.0–50.6)</td>
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<td>43.2 (38.9–48.3)</td>
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<td></td>
<td>8</td>
<td>42.3 (38.3–51.7)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Target cooking temperature was the temperature achieved by two independent internal thermocouples within each prime rib roast.

<sup>b</sup> Average (range) of five independent temperature readings obtained with a handheld thermometer after removing roasts from the holding oven (N = 4; n = 8 steaks per trial; 160 total readings).

<sup>c</sup> Average (range) of five independent temperature readings obtained with a handheld thermometer after removing roasts from the convection oven (N = 4; n = 2 steaks per trial; 40 total readings).

<sup>d</sup> Average (range) of five independent temperature readings obtained at each of four holding periods with a handheld thermometer after removing roasts from the holding oven (N = 4; n = 8 steaks per trial; 40 total readings).
At present, the U.S. Food and Drug Administration (FDA) Food Code (FDA-FC 3-401.11) (27) stipulates that both retail and food service sectors must cook nonintact beef roasts using specific cooking temperature and holding time regimens to ensure that the cooking process will be sufficient to destroy foodborne pathogens that may be internalized into the deeper tissues of the meat following enhancement processes such as blade tenderization. The FDA Food Code requires that nonintact roasts must be cooked to a minimum internal target temperature of 63°C (145°F) for 3 min. Nonetheless, retail and food service sectors commonly use a low-temperature (e.g., 48.9°C) process to prepare prime rib, with temperatures generally less than the minimum temperature specified by the FDA guidelines. For example, an informal survey conducted by Calle (6) in Lincoln, NB, in fall of 2010 revealed that restaurants typically prepare prime rib to a rare to medium rare degree of doneness by using searing, cooking, and holding regimens similar to those described herein. All six restaurants surveyed by Calle (6) prepared prime rib from boneless beef lip-on ribeye cuts that were seared on average at ca. 229.2°C (range, 204.0 to 260°C) for 15 to 40 min and then cooked on average at ca. 122.8°C (range, 107.0 to 135°C) to an instantaneous internal endpoint temperature of 48.9°C in an electric convection oven. According to Calle (6), following cooking, restaurants held prime rib roasts from 1 to 11 h at an average temperature of ca. 58.1°C (range, 48.9 to 71.0°C) in a warming oven. We validated similar commercial practices herein, and although these temperature and time parameters were effective for reducing unrealistically high levels of ECOH in mechanically tenderized prime rib roasts by ca. 3.2 to 5.2 log CFU/g, it was still possible to recover survivors by direct plating or by enrichment at all cooking temperatures tested and/or after holding cooked product for up to 8 h at 60.0°C (Table 2). Surviving ECOH, STEC, and Salmonella cells were found by both our laboratory (13, 14) and other researchers (10, 17, 29) in mechanically tenderized beef steaks after cooking. In related studies, although we observed significant reductions of ECOH and STEC (e.g., 1.5-log to 5.0-log reductions) in mechanically tenderized and/or chemically enhanced steaks that were cooked to an instantaneous internal target temperature of 37.8 to 71.1°C on an open-flame gas grill, survivors were recovered at all temperatures tested due to nonhomogeneous heating within steaks (e.g., cold spots), insulating effects caused by fat and/or connective tissues, variability in meat composition, and other factors (10, 17, 29) in an open-hearth electrical grill, although levels of ECOH detected in steaks cooked to 71.1°C were significantly lower (2.2 log CFU/g) than those from otherwise similar steaks that were cooked to 54.4°C (3.74 log CFU/g) or 68.2°C (3.3 log CFU/g).

Collectively, our results verified that commercial preparation of nonintact prime rib roasts as tested herein generates appreciable reductions in levels of ECOH that may be sporadically present at relatively low levels on the surface and/or throughout the roasts as a result of mechanical tenderization. Searing and cooking of prime rib to internal temperatures up to 71.1°C as detailed herein was not adequate to deliver a 5.0-log reduction of ECOH unless the product was subsequently held at 60.0°C for a minimum of 4 h or seared and cooked to 48.9 or 60.0°C followed by a minimum holding time of 8 h at 60.0°C. Based on these data, when prime rib is prepared from tenderized beef ribeye, to achieve a 5.0-log reduction it may be necessary to cook to temperatures higher than 71.1°C or to warm hold for an adequate time to achieve the required lethality. Our data suggest that facilities and consumers preparing prime rib should evaluate other time and temperature combinations to achieve the requisite lethality (e.g., 5.0-log reduction in ECOH). In our study, it was possible to achieve ca. 5.0-log reduction in ECOH when the product was seared, cooked to an internal temperature of 71.1°C, and held at 60.0°C for a minimum of 4 h or when it was seared and cooked to 48.9 or 60.0°C followed by a minimum holding time of 8 h at 60.0°C. The current food service industry protocols for preparation of prime rib evaluated herein may pose a public health risk when such products are prepared from blade tenderized ribeye.

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