Introduction

Non-intact beef products include ground beef, mechanically or chemically tenderized beef cuts, restructured entrees, and meat products that have been injected with brining solutions for enhancement of flavor and/or tenderness [1]. *Escherichia coli* O157:H7 or Non O157 Shiga toxin-producing *E. coli* (STEC) may be translocated from the meat surface to internal tissue by mechanical tenderization or needle injection of solutions, or entrapped in the tissue during restructuring. These processing procedures could protect the pathogens from lethal heating effects, especially if the products are undercooked [2,3].

*E. coli* O157:H7 or Non-O157 STEC can generate shiga-like toxin and cause severe hemolytic uremic syndrome in infected human bodies, and 10 cells of infection may cause a healthy person dead [4]. Since 1999, *E. coli* O157:H7 has been considered as an adulterant of raw non-intact beef products [1]. On November 2011, U.S. Department of Agriculture, Food Safety and Inspection Service (USDA-FSIS) announced that, as of June 2012, non-intact beef products would also be considered adulterated if they were contaminated with Non-O157 STEC serogroups O26, O45, O103, O111, O121, or O145 [5]. In an early report from Centers for Disease Control and Prevention (CDC), 62,000 cases of symptomatic *E. coli* O157:H7 and Non-O157 STEC contaminated in ground beef, mechanical tenderized beef, and moisture enhanced non-intact beef.

Non-O157 STEC” states that traditional cooking of non-intact steaks contaminated with Non-O157 STEC may result in the same food safety risks as shown in *E. coli* O157:H7 through consumption of undercooked contaminated products [8]. A recent study reported that, Non-O157 STEC with 9 serogroups was isolated from 300 out of 4133 ground beefs collected from 18 commercial ground beef produces [9]. This high isolation rate indicates that non-intact beefs, if contaminated or undercooked, could be a source of foodborne illness associated with Non-O157 STEC. Recent estimates indicate that Non-O157 STEC is responsible for 112,752 foodborne illnesses in the U.S. annually [7]. According to the survey, 40-58% of U.S. consumers ordered beef steaks at medium rare (60 to 62.8°C) to rare (54.4 to 57.2°C), which could be a potential threat to public health [10].

Thus, comprehensive studies of demonstrating *E. coli* O157:H7 and Non-O157 STEC lethality during common cooking practices for non-intact beef products lead a great understanding and meaningful comparative risk assessment of non-intact beef safety. This mini-review discusses the regulatory cooking recommendations and research progress related to thermal inactivation of STEC in non-intact beefs.

Regulatory cooking recommendations

The USDA-FSIS indicated that ground beef cooked to an internal temperature of at least 160°F (71.1°C) [11], and non-intact blade-tenderizer beef steaks oven-broiled to an internal temperature of 140°F (60°C) or above would not present a great risk to the consumers [2,3]. Recently, they suggested that the microbiological safety of mechanically tenderized beef steaks could be assured by cooking to an internal temperature of 71°C, or cooking to internal temperature of 63°C with rest time of 3 min [12]. They also recommended that the starting temperature of the cooking oven should be at 350°F (176°C) or no lower than 325°F (162.8°C) when cooking corned beef [13]. The North Carolina State’s Division of Environmental Health in the Department of Environment and Natural Resources stated that cooking all muscle beef such as steaks and roasts to an internal temperature of 155°F (68.3°C), as measured by a food thermometer at home, will eliminate the bacteria inside the meat [14]. In 2002, a...
comparative risk assessment for non-intact and intact beef steaks conducted by USDA-FSIS [2,3] indicated that there were insufficient data to determine whether the traditional cooking methods are adequate to destroy E. coli O157:H7 translocated during the blade tenderization process. Because proper cooking renders foods microbial safe, it is important to develop effective cooking protocols for non-intact beef products.

Research Progress of Thermal Inactivation of E. coli O157:H7 and Non-O157 STEC

Previous studies showed clearly that the lethality of STECs during and after cooking depends on multiple factors including cooked internal temperatures, cooking appliances, products’ thickness, ingredients and the location of the bacteria within the meat. Besides, E. coli O157:H7 and Non-O157 STEC behave similarly when exposed to thermal treatments. The efficacy of thermal inactivation of STECs in non-intact beefs relies on cooked internal target temperatures. An early research from Sporing [15] showed that oven-broiling 3.2 cm thick beef steaks to the internal temperature of 60 to 76.7°C resulted in a 6.5 log reduction of E. coli O157:H7. Luchansky et al. [16] reported that cooking blade-tenderized beef subprimal steaks to internal temperature ranging from 48.8 to 60°C on a commercial open-flame gas grill resulted in 2.6 to 4.6 log CFU/g reductions of surfaced inoculated E. coli O157:H7. Recently, Luchansky et al. [17] reported that cooking brine-injected steaks on a commercial open-flame gas grill to internal temperatures of 37.8°C (100°F) to 71.1°C (160°F) achieved reductions of 0.3 to 4.1 log CFU/g of E. coli O157:H7. Currently, Luchansky et al. [17] also found that cooking refrigerated, frozen, or freeze-thawed ground beef patties on commercial gas or electric grills to internal temperatures of 71.1 and 76.6°C reduced 5.1-7.0 log CFU/g of E. coli O157:H7 and Non-O157 STEC [18].

Non-intact beefs are typically prepared in commercial restaurants or consumer homes using a variety of cooking methods including broiling, grilling, frying and microwaving [19,15,2,3]. The survey of food intakes by individuals conducted by the USDA indicated that approximately 30% of consumers grill or broil steaks, while 40% of them fry steaks [20]. According to the guidelines of cooking by the American Meat Science Association, cooking methods include roasting, broiling and pan-broiling. Roasting is a method transmitting heat to the meat by convection in a closed preheated oven; broiling cooks directly through radiant heat from one direction; and pan-broiling is used for cooking thin patties by direct heat of conduction [21]. The terminologies of the cooking methods were also described by other names in different research studies, which are shown in Table 1.

Various cooking methods affected thermal inactivation efficacy of STEC in non-intact beefs. In a study to compare a double-side grill with a single side grill simulating consumer-style, Rhee et al. [22] revealed that E. coli O157:H7 reductions increased as one-turnover-single-sided grill (4.7 log CFU/g) > multi-turnover-single-sided grill (5.6 log CFU/g) > double-sided grill (6.9 log CFU/g) when ground beef was cooked to internal temperature of 71.1°C. Studies [15,23,24,25] from various research institutions suggested that broiling was the best cooking method regarding thermal inactivation of E. coli O157:H7 in non-intact beefs. Sporing [15] reported approximately 3 to 5, 4 to 6 and 5 to 6 log CFU/g reductions of E. coli O157:H7 on beef steaks cooked to the internal temperature of 65.6°C using electric skilllet frying, gas grilling and oven broiling, respectively; they also found that cooking effectiveness on pathogen inactivation increased in the order of broiling > grilling > frying. Ortega-Valenzuela et al. [23] reported that broiling was more effective in eliminating E. coli O157:H7 compared with gas grilling when the same internal temperature was reached. Similar results were also obtained by Mukherjee et al. [24]. Moreover, Yoon et al. [25] confirmed that broiling was more effective in reducing E. coli O157:H7 than grilling and pan-frying in tenderized ground beef patties when cooked to 60 or 65°C. The possible explanation is that broiling causes more even distribution of heat surrounding the samples, takes longer time to reach the final internal temperature, and allows the temperature of the product near the surface to increase more significantly than grilling or frying [15]. In a recent study conducted by the author, thermal inactivation of E. coli O157:H7 in salt and sodium-tripolyphosphate moisture enhanced reconstructed beefs increased in the order of double pan-broiling ≤ pan-broiling ≤ roasting when the internal temperature reached 65°C [26]. The author’s another study found that cooking appliance with high starting temperatures of 204-260°C resulted in greater reductions (3.3-5.5 log CFU/g) than those obtained at low starting temperature of 149°C (1.5-2.4 log CFU/g) [27]. In the same project, Adler et al. [28] found that E. coli O157:H7 survivals caused by pan-broiling increased with increasing depth of the contamination, whereas roasting in a kitchen oven showed similar pathogen survivals regardless of the depth.

In addition to the cooking methods, the thickness of non-intact beef is another factor that influences the heat transfer through the product and consequently the elimination rates of pathogens inside the steaks. Sporing [15] reported that thick steaks (3.2 cm) compared to thin ones (1.3 cm) had more reduction of E. coli O157:H7 when cooked to the same internal temperature by broiling in a standard kitchen oven. The study also found that the thick (4.0 cm) moisture enhanced non-intact beefs resulted in greater inactivation of E. coli O157:H7 than their thinner (1.5 cm or 2.5 cm) counterparts when cooked to an internal temperature of 65°C [26]. In a similar study, Adler et al. [28] observed that pan-broiling or roasting blade-tenderized beef steaks with a thickness of 2.4 cm resulted in an additional 1 log CFU/g reduction of E. coli O157:H7 compared to the 1.2 cm thick samples. This might be attributed to overheating of the thicker products due to the longer cooking time that was taken to cook them to the same internal temperature. However, Luchansky’s study [29] found that regardless of temperature or thickness, cooking 2.54 and 3.81 cm thick mechanical tenderized steaks on a commercial open-flame gas grill to internal temperatures of 48.9-71.1°C reached

<table>
<thead>
<tr>
<th>Heat transferring</th>
<th>What is stated by other studies</th>
<th>What is stated by AMSA Appliances</th>
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<tbody>
<tr>
<td>Conduction</td>
<td>Grilling (23; 24; 25)</td>
<td>Double pan-broiling George Foreman® grill (28) (26)</td>
</tr>
<tr>
<td>Conduction</td>
<td>Frying (15; 23; 24; 25)</td>
<td>Pan-broiling Presto® electric skillet (26; 27) Sanyo® grill (26;27,34)</td>
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<tr>
<td>Convection</td>
<td>Broiling (15; 23; 24; 25)</td>
<td>Roasting Oster® toaster oven (26) Magic Chef® kitchen oven (26,27)</td>
</tr>
</tbody>
</table>

Table 1: The conundrum of terminologies of cooking methods of various studies.
2.0-4.1 log (E. coli O157:H7) and 1.5-4.5 log (Non O157-STE C) reductions, respectively. They pointed out that E. coli O157:H7 and Non O157-STE C behaved similarly during heat processing, and some unexpected survivors were due to uneven heating of the products [29].

The above major factors influencing thermal inactivation of the pathogen in non-intact beefs were concluded in table 2. Additional studies showed that other factors including beef ingredients, stress adapted STEC cells, cooked beef searing time and turning over times influenced STEC reduction during thermal process. Four studies conducted by Muherjee and Yoon [30,31,32,33] indicated that lethality rate of internalized E. coli O157:H7 in marinated, tenderized, and reconstructed beef patties increased with adding organic acids (lactic, citric and acetic acid) in beef mixture. Muherjee et al. [30] found that potassium lactate protected E. coli O157:H7 in beves during thermal processing. Their study showed that addition of cetylpyridinium chloride (CPC) to the brine solution of moisture enhanced reconstructed beves resulted in the lowest number of E. coli O157:H7 survivors when the samples were cooked to 65°C [34]. The same study also found that acid stress-adapted cells were resistant to heat treatments, however, cold or desiccation stress-adapted cells were more sensitive to heat as compared with unstress-adapted E. coli O157:H7 cells [34]. In a study of investigating searing time of cooked non-intact beef, Porto-Fett et al. [35] suggested that cooking beef prime rib to internal temperatures of 48.9, 60.0, or 71.1°C with following hold at 60.0°C for ≥ 8 h could achieve a 5.0-log reduction of E. coli O157:H7. In another study of investigating the effect of steaks’ turning over times for STEC control, Gill et al. [36] observed that turning over mechanically tenderized steaks more than twice during grilling to 63°C killed all contaminated E. coli O157:H7, which achieved better pathogen inactivation effect than those cooking to 71°C with only once turning over.

Other technologies regarding inactivation of E. coli O157:H7 and Non-O157 STEC

In addition to thermal treatments, other technologies including application of surface trimming, commercial antimicrobials and probiotics (e.g. lactic acid bacteria) during non-intact beef processing were reported to effectively reduce E. coli O157:H7 and Non-O157 STEC populations. In a study of evaluating the efficacy of water-wash with beef surface trimming to inactivate E. coli O157:H7 on vacuum packaged beef trimmings. Lemmons et al. [37] reported that full surface trimming without or with water-wash reduced the pathogen populations below detectable limit. A study conducted by Echeverry et al. [38] found that spraying lactic acid bacteria, acidified sodium chloride and lactic acid on mechanically tenderized and brine enhanced beef reduced internalized E. coli O157:H7 by 1.2 to >2.2 log, and 0.8 to 3.0 log, respectively. In a similar study, Echeverry et al. [39] reported that lactic acid bacteria and lactic acid reduced internal E. coli O157:H7 up to 3.0 log and acidified sodium chloride reduced the pathogen ranged from 1.4 to 2.3. In a related study, Geornaras et al. [43] found that acidified sodium chlorite, peroxyacetic acid, or sodium metasilicate reduced E. coli O157:H7 or Non-O157 STEC on non-intact beef trimmings by 0.7 to 1.0, 0.6 to 1.0, and 1.3 to 1.5 log CFU/cm², respectively. In a related study, Fouladkhah et al. [44] found that dipping beef trimmings in 5% lactic acid of 25 or 55°C reduced E. coli O157:H7 and Non-O157 STEC by 0.5 to 0.9 and 1.0 to 1.4 log CFU/cm², respectively. Wolf et al. [45] also reported that lactic acid treatment reduced E. coli O157:H7 on beef trimmings by 0.91 to 1.41 and Non-O157 STEC by 0.48 to 0.82 log CFU/cm². A most recent study of Jadeja and Hung [46] suggested that washing beef trimming in electrolyzed oxidative water with free chlorine of 50 ppm reduced E. coli O157:H7 and Non-O157 STEC by 0.44 to 1.54 log CFU/cm². These studies clearly showed that applying commercial antimicrobials during non-intact beef processing reached averagely 0.5 to 3.0 log reduction of E. coli O157:H7 or Non-O157 STEC, which is lower than those of thermal treatments.

In conclusion, research results generated from these studies quantified the efficacies of cooking intervention as post-harvest STEC control practices applied to non-intact beef preparation at retail, foodservices, and home. They provided useful information regarding developing educational material and extension fact sheets, such as a cooking guidance manual about proper production and storage of non-intact beef for industry personnel, foodservice, and consumers, and choosing appropriate cooking approaches and degree of doneness when cooking beef products. These findings should also be useful for U.S. Department of Agriculture, Food Safety and Inspection Service USDA-FSIS to update risk assessments of E. coli O157 and Non-O157 STEC on non-intact and intact beef products.

References


**Table 2: Major thermal processing factors influencing cooking inactivation of pathogens in non-intact beefs.**

<table>
<thead>
<tr>
<th>Factors</th>
<th>Influence</th>
<th>References</th>
</tr>
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<tbody>
<tr>
<td>Cooked internal temperatures</td>
<td>The higher, the more reduction</td>
<td>[15-18]</td>
</tr>
<tr>
<td>Cooking methods</td>
<td>Broiling (roasting) is the best</td>
<td>[15,23-26]</td>
</tr>
<tr>
<td>Thickness of beef</td>
<td>The thicker, the more reduction</td>
<td>[15,26,28]</td>
</tr>
</tbody>
</table>


24. Mukherjee A, Yoon Y, Sofos JN, Smith GC, Belk KE, et al. (2007) Evaluate survival/growth during frozen, refrigerated, or retail type storage, and thermal resistance, following storage of Escherichia coli O157:H7 contamination on or in marinated, tenderized or restructured beef steaks and roasts which will minimize survival or enhance destruction of the pathogen.


