K-STATE
Kansas State University
Animal Sciences and Industry
K-State Research and Extension
232 Weber Hall
Manhattan, KS 66506-0201
785-532-6533
Fax: 785-532-7059

March 17, 1999

(36)

Docket Clerk
USDA-FSIS
Cotton Annex Building
300 12 Street SW, Room 112
Washington, DC 20250

97-068N
97-068N-36
James L. Marsden
Randall K. Phebus

RE: Docket Number 99008-N

On behalf of Kansas State University, I am submitting the attached research report on evaluation of *E. coli* O157:H7 in blade tenderized (non-intact) steaks cooked to rare to well-done temperatures as a comment to the agency's policy on *E. coli* O157:H7 contaminated beef products. In this study, we intentionally inoculated beef cuts with high levels of *E. coli* O157:H7 in order to quantify the effect of mechanical tenderization on the translocation of bacteria from the surface of beef cuts into interior muscle. *E. coli* O157:H7 was used in order to obtain data specific to the pathogen of concern. The levels of contamination used in this study do not reflect levels that are likely to be present. In actual practice, the source point of contamination for *E. coli* O157:H7 is at the carcass level and contamination is prevented or reduced through the application of HACCP, including validated anti-microbial technologies and compliance with the agency's policy of zero tolerance for physical defects. The potential for contamination is further reduced by the removal of the carcass surface by trimming before mechanical tenderization. Even by applying worse than worse case inoculation levels, our study based on the oven broiling method of cooking, demonstrated that there is no difference in risk between intact and non-intact steaks over the range of cooking temperatures from rare to well-done. Both intact and non-intact steaks are safe for consumers when cooked under these conditions.

This study is being submitted to FSIS at this time in order to meet the March 22, 1999 deadline for comments. The research that forms the basis for this comment will also be written as a scientific paper for submission to a peer reviewed journal.

Please advise if additional information is required.

Sincerely,

James L. Marsden
Regents Distinguished Professor
of Meat Science

Randall K. Phebus
Associate Professor
Food Microbiology

/am

Escherichia coli O157:H7 Risk Assessment for Production and Cooking of Blade Tenderized Beef Steaks

Principle Investigators:

Randall K. Phebus, Ph.D.	rphebus@oz.oznet.ksu.edu
James L. Marsden, Ph.D.	jmarsden@oz.oznet.ksu.edu
Harshavardhan Thippareddi, Ph.D.	hthippar@oz.oznet.ksu.edu
Sarah Sporing, GRA	sarah@ksu.edu

Collaborators:

Kansas State University
Kansas Beef Council
Cargill, Inc
Ross Industries
Food Safety Consortium
NCBA

Presented at the USDA-FSIS Public Meeting
March 8, 1999
Washington, DC

ABSTRACT

The potential for translocation of organisms from the surface of whole muscle to the interior of muscle via the blade tenderization process was evaluated. In Study One, beef top sirloin subprimals were inoculated with 10^6 cfu/cm^2 of *Escherichia coli* O157:H7, and passed once through a blade tenderizer. Core samples were aseptically removed from the subprimals and sliced into cross-sectional strips. Results indicate that the blade tenderization process transfers 3-4% of surface contamination to the interior of the muscle. Study Two evaluated thermal destruction of *E. coli* O157:H7 in blade tenderized steaks under an oven broiling element. Six top sirloin subprimals were inoculated with a five strain cocktail to a level of ca. 10^7 cfu/cm^2 on the top surface. Three subprimals were passed once through a tenderizer and the other three were left non-tenderized to serve as controls. Steaks of varying thicknesses (i.e. weights) were cut from each of the subprimals and cooked to one of six endpoint temperatures (120, 130, 140, 150, 160, and 170°F). After removal from the oven, steaks were immersed in an ice bath to halt thermal lethality, and cooled to a temperature below 100°F before sampling. A target internal temperature of 120°F produced greater ($p \leq 0.05$) log reductions (cfu/g) in non-tenderized (NT) vs. tenderized (T) steaks (5.2 log reduction vs. 3.2 log reduction). At 130°F, T and NT steaks produced 5.6 and 5.0 log reductions, respectively, which was not significantly different, likely due to high standard deviations in bacterial counts, especially in low weight steaks. At endpoint temperatures of 140°, 150°, 160° and 170°F, log reductions were greater than 6 logs in both T and NT steaks, which represented virtually complete destruction. It was observed that even after immersion in an ice bath, internal temperatures continued to rise above the target temperatures by as much as 11°F (in 5 oz steaks). In food service application, where steaks would not be rapidly cooled in this manner, an additional margin of safety would be incorporated into the cooking process. At cooking temperatures ranging from rare (130°F) to well done (170°F), there were no differences in *E. coli* O157:H7 between intact and non-intact steaks using the oven broiling method. Both intact and non-intact steaks are safe for consumers when cooked to the endpoint temperatures evaluated in the study by the oven broiling method.

INTRODUCTION

Beef has long been considered a staple of the American diet, due to its availability and versatility. However, the beef industry must provide consistent quality and uniformity in its products to remain competitive. Most consumers judge quality and overall acceptability of beef products based on tenderness. Blade tenderization is one of the most effective and efficient technologies currently used to ensure tenderness.

While sensory characteristics of blade tenderization have been extensively researched, microbiological aspects of the process have not been investigated to the same degree. Although the generic microbiological quality of blade tenderized muscle has been shown to be equivalent to non-tenderized controls (Boyd et al., 1978), bacteria were translocated into the interior of the muscle (Johnston et al., 1979). Therefore, research is required to quantify this bacterial relocation, identify critical control points to minimize the risk for pathogenic contamination, and define effective control measures (cooking schedules) for resultant products. The National Advisory Committee on Microbiological Criteria for Foods (NACMCF), Meat and Poultry Subcommittee (1997) stated that "*Due to the low probability of pathogenic organisms being present in or migrating from the external surface to the interior of beef muscle, cuts of intact muscle (steaks) should be safe if the external surfaces are exposed to temperatures sufficient to effect a cooked color change.*" However, if the surface of an intact muscle or muscle system is violated by mechanical tenderization (blade tenderization), contamination may be carried from the surface to the interior of the cut. The NACMCF, Meat and Poultry Subcommittee (1997) stated that there is a lack of scientific data to address the hazards associated with those processes that may cause translocation of pathogens. Because of the widespread use of the blade tenderization technology and the potential food safety risks it may pose, the Beef Industry Food Safety Council (BIFSCO) identified this research as a priority for the beef industry. This industry group facilitates input from producers, packers, processors, distributors, restaurants, and food retailers in an effort to identify and implement workable *E. coli* O157:H7 controls in the beef industry.

Research is required to establish processing and preparation protocols to ensure safety of blade tenderized beef products. Unlike ground beef, which is almost exclusively cooked to 160°F by food service establishments as a result of USDA and state health department recommendations, mechanically tenderized steaks are often perceived as whole muscle cuts and are, therefore, prepared to customer specifications, which could potentially pose a health risk to consumers. By characterizing the process and validating cooking protocols for destruction and elimination of *E. coli* O157:H7, suppliers and food service will be able to effectively establish standard cooking recommendations for preparation of these products.

MATERIALS AND METHODS

Study One: Penetration of *E. coli* O157:H7 during Blade Tenderization

Bacterial Cultures

A rifampicin-resistant *E. coli* O157:H7 (USDA-FSIS 011-82) was used as a marker strain in the study. Rifampicin resistance was confirmed by growing the culture at 35°C for 24 hours in Tryptic Soy Broth (TSB, Difco, Detroit, MI) and streaking on Tryptic Soy Agar with 0.1% rifampicin (TSA-rif). The culture was grown in TSB (100 mL) at 35°C for 12 hours, and centrifuged (Beckman Instruments, Redmond, WA; 10,000 rpm, 10 min., 4°C). Culture pellets were resuspended in peptone water (PW, 0.1%) and serially

diluted (PW) to achieve high and low inoculum levels (10^9 and 10^6 CFU/mL respectively).

Inoculation and Blade Tenderization of Subprimals

Vacuum packed subprimals (top butt; cap removed) were obtained from a meat processor and stored under refrigeration. The subprimals were surface inoculated in a specially designed inoculation chamber (Nutsch, 1998) by misting the culture suspension. Dripping and seepage of the inoculum to the bottom surface of the subprimal was prevented by placing paper towels around the subprimal. The subprimals were stored at 4°C for 30 minutes to allow for bacterial attachment.

After bacterial attachment, each of the inoculated subprimals was passed once through the blade tenderizer (Ross TC700M, Midland, VA; Fig. 1) which produces 32 penetrations/in^2 (Figs. 2, 3, and 4). The unit was disassembled, cleaned and sanitized between passage of each subprimal (low and high levels of inoculation) to prevent any cross-contamination. The subprimals were then stored in a freezer (at 0°C) for three hours to crust the surface to facilitate obtaining the core samples.

Microbiological Sampling

The subprimals were aseptically transferred onto a fresh sheet of butcher paper and inverted, with the inoculated surface facing down. Four cores were obtained from each subprimal, using sterile coring devices (4 in. length; 2 in. diameter), starting from the non-inoculated surface. Care was taken to prevent the cored meat from passing through the inoculated surface of the coring device. Approximately 2 mm of the non-inoculated surface were aseptically removed and the cores were sliced into four cross-sectional strips (2 cm, 2cm, 1cm, and 1cm from non-inoculated surface) using a sterile cutting guide.

Cross-sectional strips were weighed and aseptically transferred to a blender jar (Oster®, Schaumburg, IL), diluted with peptone water (to produce a 1:4 dilution) and blended for 30 seconds. The resulting slurry was then poured into a sterile filter stomacher bag, serially diluted and plated on TSA-rif. The plates were incubated at 35°C for 24 h and enumerated. Typical colonies were confirmed serologically with a latex agglutination assay (RIM *E.coli* O157:H7; Remel, Lenexa, KS).

Statistical Analysis

The data were analyzed by analysis of variance using the General Linear Model procedure of Statistical Analysis System (SAS Institute, Inc., Cary, NC, 1990). LSD was used to separate means of the log CFU/g of the cross sectional strips.

Study Two: Destruction of *E. coli* O157:H7 in Blade Tenderized Beef Steaks by Broiling

Bacterial Cultures

Fresh cultures of *Escherichia coli* O157:H7 (five strains; USDA-FSIS 011-82, USDA-FSIS 45756, ATCC 43888, ATCC 43889, and ATCC 43890) were inoculated separately into TSB (100 mL) and incubated for 18 hours at 35°C. The cultures were centrifuged (Beckman Instruments, Redmond, WA; 10,000 rpm for 10 min at 4°C), cell pellets were resuspended in peptone water (PW; 50 ml, 0.1%), and combined to provide a five strain cocktail of mixed strain inoculum. Serial dilutions of the mixed inoculum were prepared, spiral plated on MacConkey Sorbitol agar (MSA), incubated at 35°C for 24 h and enumerated.

Experimental Design

Six top butt subprimals were mist inoculated with a five-strain cocktail of *Escherichia coli* O157:H7 to a level of 10^7 cfu/cm^2 on the top exterior surface. After a one-hour attachment period at 4°C, three of the subprimals were tenderized; the other three were left non-tenderized to serve as controls. Steaks of three varying weights (i.e. thicknesses) were then randomly cut from the inoculated subprimals. Tenderized and non-tenderized steaks of each weight group were cooked to one of six internal endpoint temperatures under an oven broiling element. After removal from the broiler, the steaks were immersed in an ice bath and the internal temperature of each steak was monitored until it fell below 100°F. Cross-sectional samples were collected, which represented the inoculated surface and the interior of the muscle. An identical sample was taken from an uncooked steak of the same treatment and weight group to serve as a control. Each sample was then plated on MacConkey Sorbitol Agar and Phenol Red Sorbitol Agar and enumerated after 24 hours of incubation at 35°C. Forty-two samples (2 treatments X 3 weights X 7 temperatures, including raw controls) were analyzed per trial, with three replications completed. Temperature and enumeration data were compiled from the 126 samples and were evaluated using Statistical Analysis System (SAS Institute, Inc., Cary, NC., 1990). The General Linear Models procedure was used to determine differences between treatments.

Inoculation and Blade Tenderization of Subprimals

Six vacuum-packaged top butt subprimals, with caps removed, were received from a commercial slaughter plant and stored under refrigeration at 4°C. Inoculation was performed as described (using high inoculum level) in the penetration study. The subprimals were stored at 4°C for 1 hour to allow for bacterial attachment.

After bacterial attachment, three randomly selected inoculated subprimals was passed through the blade tenderizer (Ross TC700M, Midland, VA). The remaining subprimals were left non-tenderized to serve as controls. The unit was disassembled, cleaned and sanitized between passage of each subprimal to prevent any cross-contamination. All subprimals were then randomly cut into steaks of three different thicknesses (0.50, 0.75 and 1.25 in.) and trimmed to weights of 5, 8 and 12 oz. (142, 226, and 340g), respectively, to simulate standard industry specifications.

Cooking of Steaks

A type T thermocouple (Omega Engineering, Stamford, CT) was inserted into the geometric center of each by passing the wire through the edge of each steak, avoiding fat seams and loose-structured lean tissue. The steaks were placed on an oven broiler pan approximately four inches from the broiling element of a standard kitchen oven (Whirlpool Corp., Benton Harbor, MI). The oven was programmed for broil, at 500 °F, and the ambient oven temperature at the surface of the broiler pan was ca. 300°F. Steak temperature at the geometric center was monitored at 10 second intervals, using a data logger (National Instruments, Austin, TX). The steaks were flipped at the midpoint between the initial temperature and the target endpoint temperature. To avoid cross-contamination of the cooked top surface of the steaks after turning, two steaks were cooked in adjacent quadrants and turned over onto the opposite clean quadrants of the broiler pan. The steaks were cooked to target endpoint temperatures of 120, 130, 140, 150, 160, and 170°F, corresponding to undercooked, rare, medium rare, medium, medium well, and well done cooking temperatures. An uncooked steak from each treatment served as a control.

When target internal temperatures were reached, the steaks were removed from the oven and immediately placed in sterile plastic stomacher bags, and immersed in an ice bath for rapid cool-down. The steaks were removed from the ice bath and sampled when the internal temperature cooled to below 100°F.

A cross-sectional strip from the center of each steak, parallel to the blade penetrations was aseptically excised, representing both the inoculated surface and the interior of the steak. The strip width was varied depending on the thickness of the steak: 2 in., 1.5 in., and 1 in. strips from the 5, 8, and 12 oz steaks to obtain a uniform sample size and number of blade penetrations. The samples were placed in sterile Waring blender jars, PW was added (to produce a 1:5 dilution) and the samples were blended for 30 seconds.

Enumeration of E. coli O157:H7 Populations

Sample suspension was serially diluted in PW and plated on MacConkey Sorbitol Agar (MSA) and Phenol Red Sorbitol Agar (PRSA) by spiral and spread plating methods. PRSA was used to recover the sublethally injured cells. Plates were incubated at 37°C for 24 h and enumerated. Typical colonies (sorbitol negative) were confirmed serologically using a latex agglutination assay (RIM *E.coli* O157:H7, Remel, Lenexa, KS). Samples testing negative by direct plating methods were evaluated qualitatively for *E. coli* O157:H7 by enrichment in mEC broth. The enriched samples were analyzed culturally on MSA and Tryptic Soy Agar, and biologically confirmed (API 20E, bioMeriuex Vitek, Inc., Hazelwood, MO). The difference in *E. coli* O157:H7 counts between the control, non-cooked steak and the cooked steak were calculated and reported as reductions.

Statistical Analysis

Forty-two treatments were analyzed per trial, with three replications completed. The data were analyzed by analysis of variance using the General Linear Model procedure of Statistical Analysis System (SAS Institute, Inc., Cary, NC; 1990). Fisher's LSD was used to separate mean reductions of *E. coli* O157:H7 for each of the cooking temperatures. All possible interactions of treatment (blade tenderized vs. non-tenderized), weight of steaks (5, 8, and 12 oz), and target cooking temperatures were evaluated.

RESULTS AND DISCUSSION

Study One: Penetration of *E. coli* O157:H7 during Blade Tenderization

E. coli O157:H7 present on the surface of the subprimals was translocated throughout the interior of the muscle during blade tenderization (Fig. 5). The high level inoculum was applied at a level of 6 log cfu/g over the top 1 cm strip, and although a dilution effect was seen throughout the core, approximately 3 logs of *E. coli* O157:H7 were recovered at a depth of 6 cm. The geometric center of the core, which in regard to steak cooking, is the slowest to reach a target temperature, harbored 4 logs of *E. coli* O157:H7. The low inoculum (3.2 log cfu/g on surface) produced a similar trend, showing the relocation of approximately 1.8 logs to the geometric center of the steaks. Overall, the process was found to carry 3-4% of the surface organisms to the center of the core, regardless of surface inoculation level.

Johnston et al. (1978) showed similar results, indicating translocation of *Salmonella newport* from the surface, into beef roasts, even with a low inoculum level of ca. 2 log cfu/cm^2. The authors reported that

surface bacteria can penetrate muscle surfaces without the assistance of a physical process such as blade tenderization. However, the levels of *Salmonella newport* were one log higher in inoculated blade tenderized roast compared to inoculated, non-tenderized roast, indicating the translocation.

Reports by Gill and Penney (1977; 1982), Maxcy (1981), and Sikes and Maxcy (1980) indicated that microorganisms penetrate the surface of post-rigor muscle, to depths of 20-40 mm, during storage at elevated temperatures (up to 37 °C), depending on the type of organism (and its ability to produce proteolytic enzymes), and the type and structure of meat. Sikes and Maxcy (1980) reported that the orientation of the muscle fiber affects the bacteria penetration to the interior of the muscle. Thus, in the event of pathogen contamination on the surface of a subprimal, and assuming cross contamination during fabrication process, it is possible that the pathogens could be found in the interior of a steak. However, the extent and depth of penetration would depend on the type of the organism, temperature of storage, orientation of the muscle fiber at the point of contamination and length of storage.

De Zuniga et al. (1991) and Anderson et al.. (1992) reported that spray washing the beef carcasses with water under pressure resulted in penetration of a blue lake (water insoluble dye). The authors hypothesized that the bacteria present on the surface of the meat animal during slaughter would penetrate into the muscle tissue. They used blue lake to simulate bacteria to facilitate visualization of the depth of penetration as the blue lake particles (0.6 μm) are only slightly smaller than the size of most bacteria (2-6 μm).

In the present study, use of marker *E. coli* O157:H7 strain allowed us to quantify the translocation accurately, which would not be possible otherwise. These results provide a significant insight into the rate of translocation of the surface bacteria during blade tenderization. Similar methods of physical manipulation of the intact muscles, such as tumbling, would also translocate the surface microflora into the interior of the muscle. The depth of penetration of microbial cells would depend on the type and extent of manipulation of the muscle tissue.

In view of the ability of microorganisms to penetrate the muscle tissue and translocate into the interior of the muscle, and the translocation of the microbial cells due to physical processes like blade tenderization and related processes, it is necessary to evaluate and validate cooking parameters/temperatures that would minimize/eliminate the risk of foodborne pathogens in intact as well as non-intact muscle foods.

Study Two: Destruction of *E. coli* O157:H7 in Blade Tenderized Beef Steaks by Broiling

Initial statistical analysis of all main effects (treatment, weights, and temperature) and all possible combinations of interaction, with bacterial reduction as the dependent variable, revealed a significant ($p \leq 0.05$) interaction between the treatment (tenderized vs. non-tenderized) and temperature. Data were pooled across the three weights and treatments were compared within each individual temperature. At 120°F internal target temperature, non-tenderized steaks showed significantly greater reductions compared to tenderized steaks (5.2 log reduction vs. 3.2 log reduction)(Fig. 6). This finding indicates that while an internal temperature of 120°F yields a surface temperature sufficient to kill 5 logs of *E. coli* O157:H7, all of which are on or near the surface of non-tenderized steaks, it is not high enough to eliminate the bacteria translocated to the interior of the tenderized steaks.

At 130°F, tenderized and non-tenderized steaks produced 5.6 and 5.0 log reductions, respectively. This

difference was not statistically significant, likely due to the high standard deviations in bacterial reductions, especially in low weight steaks. Preliminary analysis showed standard deviations up to 1.1 logs in tenderized steaks and as high as 1.7 logs in non-tenderized steaks. Although 5 log reductions were achieved for both intact and non-intact steaks, the high degree of variation may reduce the margin of safety associated with a 130°F cooking protocol.

Johnston et al. (1978) reported that salmonellae survived on both the surface and in the core of mechanically tenderized roasts oven cooked to an internal temperature of 130°F. The authors hypothesized that the presence of viable salmonellae on surface could be either due to purging of the cells from the center or survival on the surface. Johnston et al. (1978) concluded that tenderized roasts cooked to 130°F may be a public health problem.

The authors did not evaluate the effect of cooking inoculated, non-tenderized roasts to 130°F. Further, the authors used beef roasts (5 lb) in the experiment, whereas the present study evaluated the microbial reductions that could be achieved in steaks processed from the roasts (subprimals) to more accurately resemble the restaurant operations. In addition, use of a larger mass of meat (5 lb) and heating to an internal temperature of 130°F would have resulted in a further increase in temperature, higher than what we observed in our study, resulting in higher lethalities and reductions in salmonellae.

Log reductions at 140° F were greater than 6 logs and no significant difference was observed between treatments. At 150°, 160°, and 170°, there was a significant difference between treatments, although that difference was only 0.2 logs. This significance correlates to the difference in mean bacterial counts found between tenderized and non-tenderized raw samples in the preliminary analysis. At each of these temperatures, both treatments achieved greater than 6.2 log reductions, which represents virtually complete destruction.

The experimental design of this study incorporated the use of an ice bath to rapidly halt thermal lethality in the steaks after removal from the broiler, to provide more accurate information concerning thermal destruction achieved at the identified target internal temperatures. It is important to note that even after transfer to the ice bath, internal temperatures of the steaks continued to rise above these target temperatures, by as much as 11 °F (Figs. 7-9). Temperature increases tended to be larger at the low target temperatures, but no significant differences were observed within treatments or steak weights. In food service applications, the finished product would not be cooled as in this scientific study, and internal temperatures would likely rise to higher endpoints and will be maintained for longer periods of time, thereby resulting in increased margin of safety in regard to pathogen destruction.

Carpenter and Harrison (1989) reported that the cooking temperatures applied in the study (150 – 180 °F) were insufficient to totally eliminate the high population of *L. monocytogenes* inoculated into the tissue. The authors reported that dry heat used in the study was a less effective method for killing microorganisms compared to moist heat, and evaporation occurring at the surface of the chicken breast due to dry heating method could be favoring survival of the organism. As the meat is cooked, the surface will have lower water activity (a_w) due to progressive drying of the surface tissue. Juices from the interior of the muscle flow to the surface and probably buffer the surface from increasing temperatures due to evaporation. A similar evaporative phenomenon was reported by Blankenship (1978), Blankenship and Craven (1982), and Blankenship et al. (1980). Blankenship (1978) observed that surviving *Salmonella typhimurium* populations

were probably located only on or very near the surface of beef roasts cooked to highest internal temperature of 147.5 °F, with long come-up times (126 min above 135°F at the center of the roast).

The results reported herein are incomplete and large amounts of data are currently being analyzed. This data includes calculation of F-values, determination of sub-lethal *E. coli* O157:H7 injury during cooking, and evaluation of different cooking methods.

SUMMARY AND CONCLUSIONS

Results of this study indicate that while the blade tenderization process does translocate a significant number of surface organisms (3-4%) into the interior of the muscle, which are protected from mild heat treatments, the potential of a public health hazard caused by this process can be controlled if proper cooking schedules are followed. Further, the data shows that there is no difference in risks between intact (non-tenderized) and non-intact (tenderized) steaks at cooking temperatures ranging from rare (130°F) to well done (170°F). Both intact and non-intact steaks are safe for consumers, when cooked to the internal temperatures of rare to well done using an oven broiling method.

In this study, we intentionally inoculated beef cuts with high levels of *E. coli* O157:H7 in order to quantify the effect of mechanical tenderization on the translocation of bacteria from the surface of the beef cuts into interior of the muscle. *E. coli* O157:H7 was used in order to obtain data specific to the pathogen of concern. The levels of contamination used do not reflect levels that are likely to be present. In actual practice, the source point of contamination for *E. coli* O157:H7 is at the carcass level and contamination is prevented or reduced through application of numerous processing steps, including validated anti-microbial technologies and enforcement of USDA-FSIS's zero tolerance policy for physical defects. The potential of contamination is further reduced by the removal of the carcass surface by trimming before mechanical tenderization.

A target internal temperature of 140°F appears to provide the necessary thermal destruction required to virtually eliminate *E. coli* O157:H7 risk. By including validated antimicrobial intervention strategies in the slaughter and fabrication processes to improve initial microbial quality of products destined for blade tenderization, the likelihood of pathogenic contamination is further decreased, thus decreasing the level of process lethality required during cooking of tenderized cuts.

This study only lends insight into control of risks in blade tenderized steaks using oven broiling. This method of cooking applies a uniform temperature to the steaks compared to preliminary studies performed in our laboratory using a commercial gas charbroiling grill and flat surface electric grills. More intensive evaluations of these cooking methods for adequate risk control are warranted. Comprehensive data and interpretations will be provided to the Agency as they become available.

REFERENCES

Anderson, M. E., R. T. Marshall, and J. S. Dickson. 1992. Estimating depths of bacterial penetration into post-rigor carcass tissue during washing. J. Food Safety. 12: 191-198.

Blankenship, L. C. 1978. Survival of a *Salmonella typhimurium* experimental contaminant during cooking of beef roasts. Appl. Environ. Microbiol. 35: 1160-1165.

Blankenship, L. C., and S. E. Craven. 1982. *Campylobacter jejuni* survival in chicken meat as a function of temperature. Appl. Environ. Microbiol. 44: 88-92.

Blankensip, L. C., C. E. Davis, and G. J. Magner. 1980. Cooking methods for elimination of *Salmonella typhimurium* experimental surface contaminant from rare dry roasted beef roasts. J. Food Sci.45: 270-273.

Boyd, K.J., H.W. Ockerman and R.F. Plimpton. 1978. Sensory characteristics and microbiological evaluation of stored mechanically tenderized beef semimembranosus muscle. J. Food Sci. 43:670-676.

Carpenter, S. A., and Harrison, M. A. 1989. Survival of *Listeria monocytogenes* on processed poultry. J. Food Sci. 54: 556-557.

De Zuniga, A. G., M. E. Anderson, R. T. Marshall, and E. G. Ianotti. 1991. A model system for studying the penetration of microorganisms into meat. J. Food Prot. 54: 256-258.

Gill, C. O., and N. Penney. 1977. Penetration of bacteria into meat. Appl. Environ. Microbiol. 33: 1284-1286.

Gill, C. O., and N. Penney. 1982. Bacterial penetration of muscle tissue. J. Food Sci. 47: 690-691.

Johnston, R.W., M.E. Harris, and A.B. Moran. 1977. Effect of mechanical tenderization on beef rounds inoculated with salmonellae. J. Food Safety 1:201-209.

Maxcy, R. B. 1981. Surface microenvironment and penetration of bacteria into meat. J. Food Prot.44: 550-552.

Nutsch, A. L. 1998. Bacterial decontamination of meat surfaces through the application of a steam pasteurization process. Ph. D. Dissertation, Kansas State University, Manhattan, KS.

SAS, 1990. Statistical Analysis System. User's guide. 4th Ed. SAS Institute, Inc., Cary, NC.

Sikes, A., and Maxcy, R. B. 1980. Postmortem invasion of muscle food by a proteolytic bacterium. J. Food Sci. 45: 293-296.

LEGEND TO FIGURES:

Fig. 1. Photograph of Ross TC700M Blade Tenderization unit.

Fig. 2. Photograph of blade head (produces 32 penetrations/in^2) for the Ross TC700M Blade Tenderization unit.

Fig. 3. Schematic of blade tenderization process, step 1 (prior to penetration).

Fig. 4. Schematic of blade tenderization process, step 2 (during penetration).

Fig. 5. Contamination profile of tenderized beef subprimals, with low (ca. 10^3 cfu/g) and high (ca. 10^6 cfu/g) levels of *Escherichia coli* O157:H7 on the surface.

Fig. 6. Reductions in *Escherichia coli* O157:H7 in tenderized and non-tenderized steaks cooked to various endpoint temperatures.

Fig. 7. Maximum internal temperatures reached in 5 oz tenderized and non-tenderized steaks cooked to six target endpoint temperatures.

Fig. 8. Maximum internal temperatures reached in 8 oz tenderized and non-tenderized steaks cooked to six target endpoint temperatures.

Fig. 9. Maximum internal temperatures reached in 12 oz tenderized and non-tenderized steaks cooked to six target endpoint temperatures.

Fig. 1

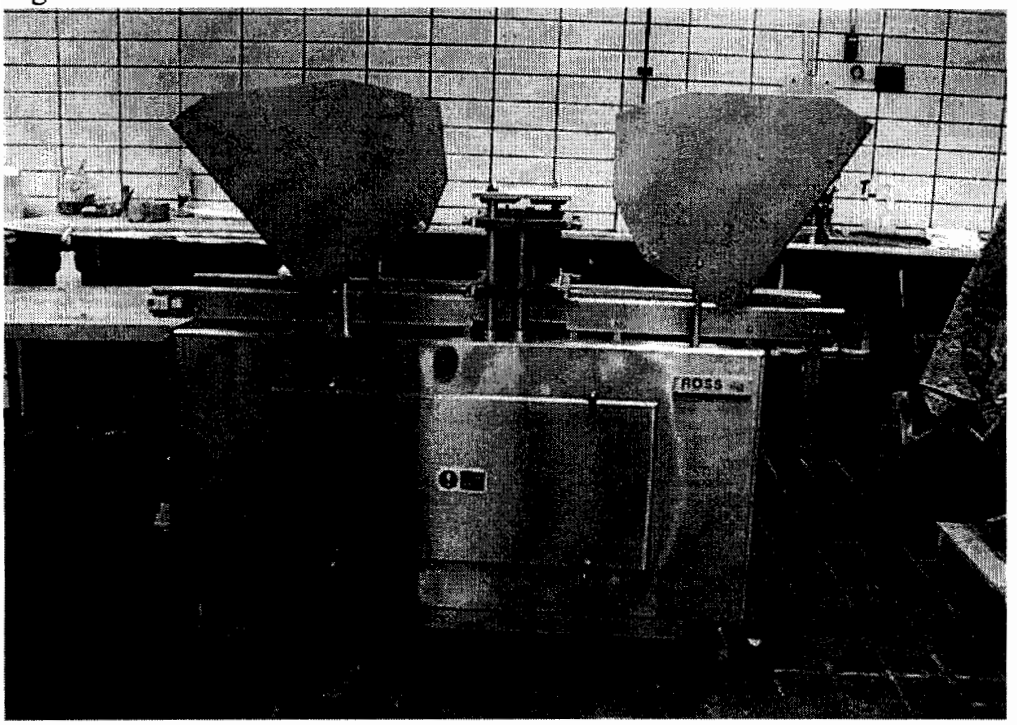


Fig. 2.

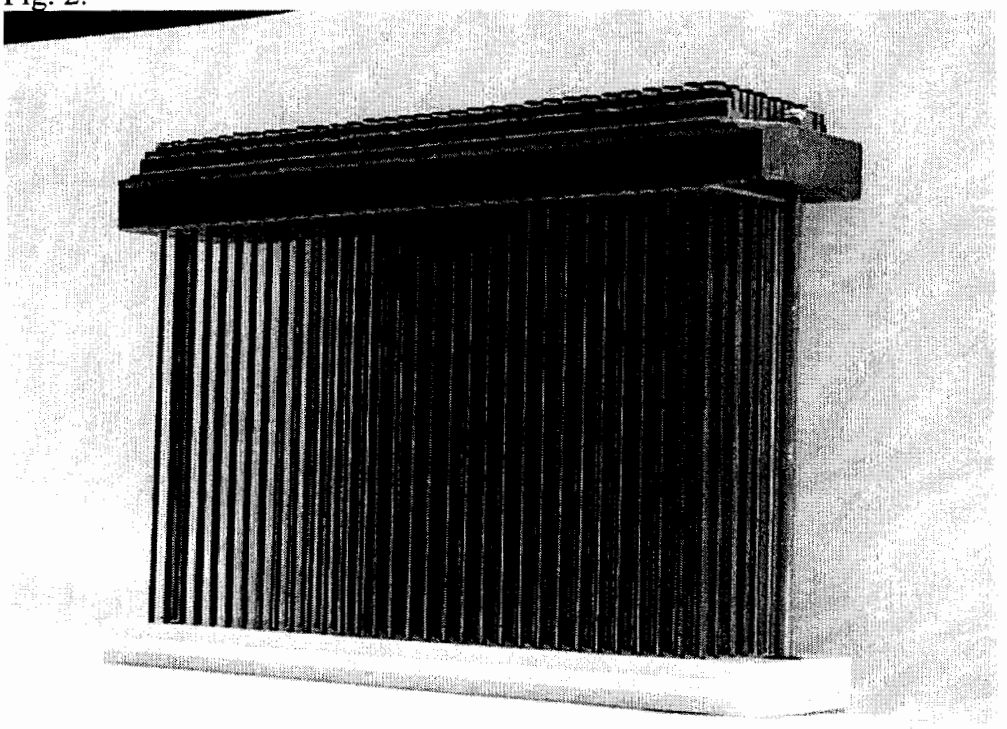


Fig. 3.

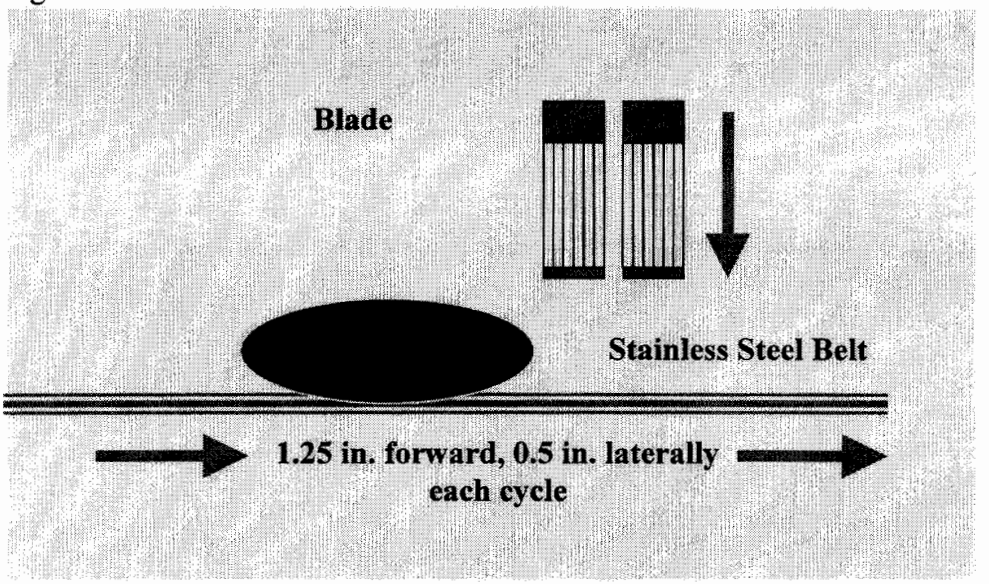

Blade
Stainless Steel Belt
1.25 in. forward, 0.5 in. laterally each cycle

Fig. 4

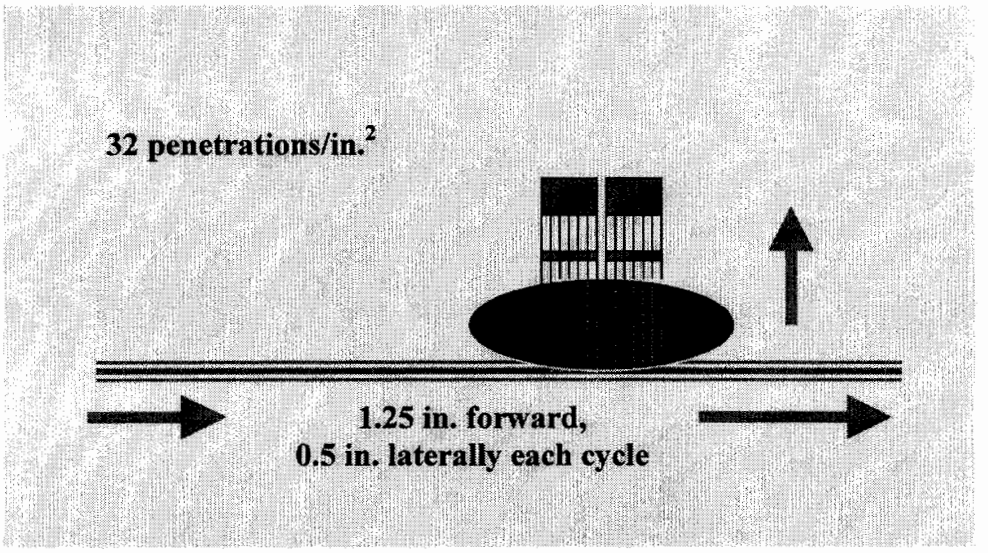

32 penetrations/in.^{2}
1.25 in. forward,
0.5 in. laterally each cycle

Fig. 5

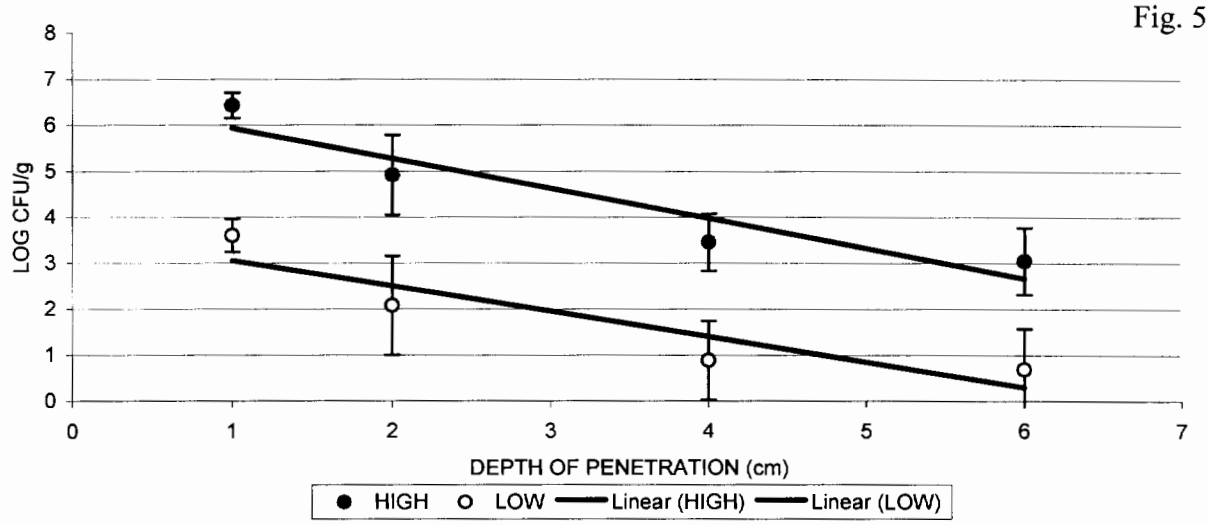

LOG CFU/g
0
1
2
3
4
5
6
7
8
DEPTH OF PENETRATION (cm)
HIGH
LOW
Linear (HIGH)
Linear (LOW)

Fig. 6

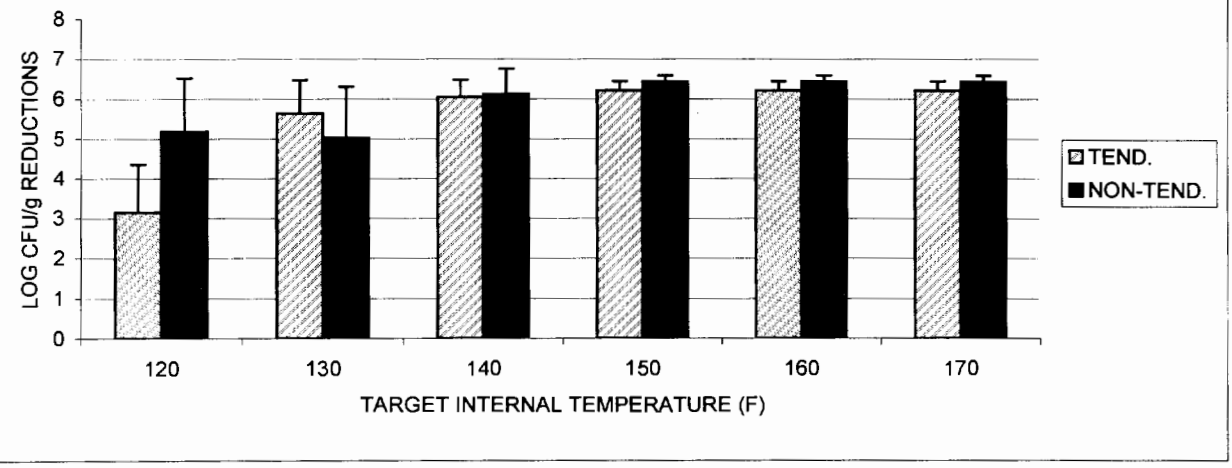

LOG CFU/g REDUCTIONS
0
1
2
3
4
5
6
7
8
120
130
140
150
160
170
TARGET INTERNAL TEMPERATURE (F)
TEND.
NON-TEND.

Fig. 7

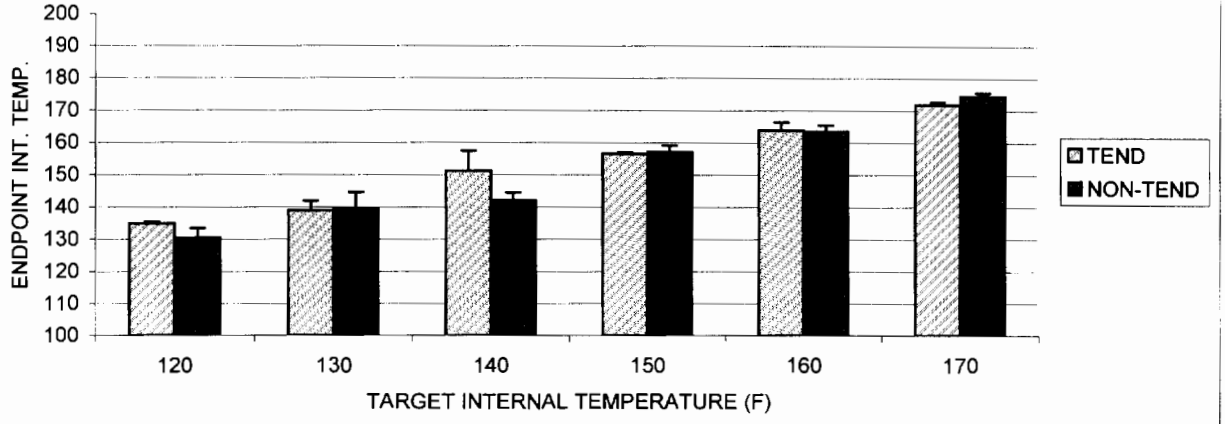

200
190
180
170
160
150
140
130
120
110
100
ENDPOINT INT. TEMP.
120
130
140
150
160
170
TARGET INTERNAL TEMPERATURE (F)
TEND
NON-TEND

Fig. 8

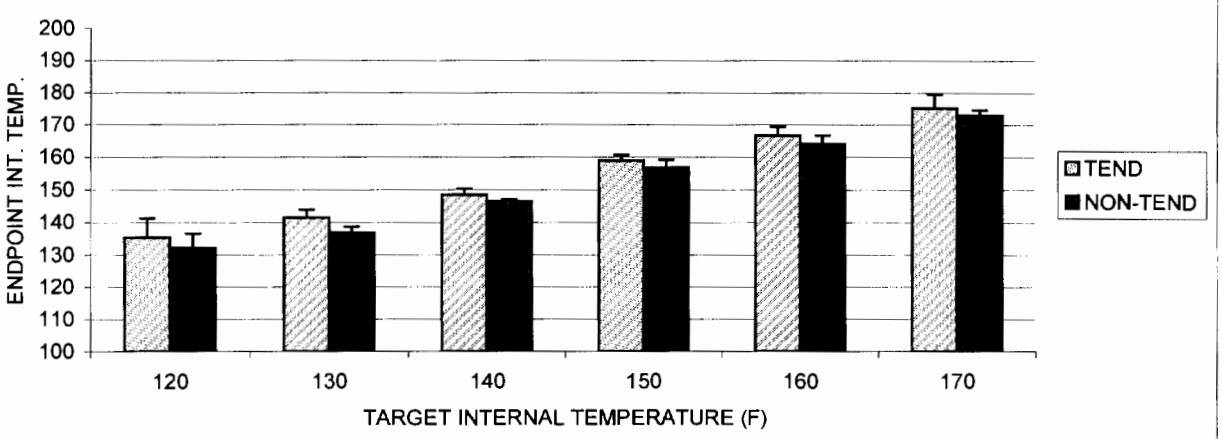
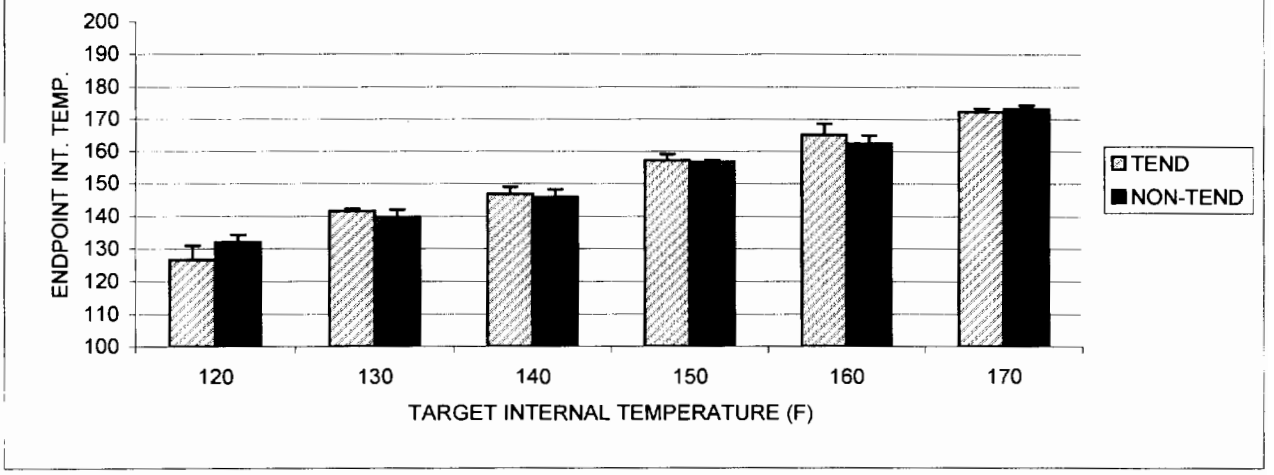

200
190
180
170
160
150
140
130
120
110
100
ENDPOINT INT. TEMP.
120
130
140
150
160
170
TARGET INTERNAL TEMPERATURE (F)
TEND
NON-TEND

Fig. 9


200
190
180
170
160
150
140
130
120
110
100
ENDPOINT INT. TEMP.
120
130
140
150
160
170
TARGET INTERNAL TEMPERATURE (F)
TEND
NON-TEND