EFFECTS OF BEEF CARCASS ELECTRICAL STIMULATION AND HOT BONING ON MUSCLE pH DECLINE RATES AND SENSORY CHARACTERISTICS OF FRESH AND FROZEN STEAKS

by

JOY EUGENIA BOWLES

B.S., University of Tennessee, 1979

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

FOOD SCIENCE

Department of Animal Sciences and Industry

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1981

Approved by:

Curtis L. Kastner

Major Professor

ACKNOWLEDGMENTS

Utmost gratitude is expressed to the author's major professor, Dr. Curtis L. Kastner, for his guidance, counseling, and friendship. The author wishes to express her increased admiration of Dr. Kastner for his unique approach to professional and personal development of his graduate students. The author would like to thank the members of her advisory committee, Dr. Don Kropf, Dr. Melvin Hunt, and Dr. Michael Dikeman, for the support, suggestions, and encouragement given during my studies towards the Master's of Science degree.

Thanks go to research assistants, Jennifer Kendall and Frank Russo for their technical assistance in collecting and analyzing samples and to the following graduate students for their help and friendship throughout my graduate studies: Jim Claus, Pedro deFelicio, Dan Hale, Steve Olsen, B. R. Rao, and Pam Sleper.

The author extends a very special thanks to her parents, Mr. and Mrs. James Bowles, her sister, Dixie, and her fiance, Dirk Axe, for their steadfast support, love, and encouragement during my Master's program.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ORGANIZATION OF THE THESIS

This thesis is presented in a series of chapters. Chapter I is a general introduction to the thesis. Chapter II includes a general review of literature pertaining to all topics discussed herein. The two chapters following the general review of literature are separate but related studies that are representative of technical papers that will be submitted for publication.

Chapter V is an appendix which includes detailed analysis of variance tables, sample calculations used for mean comparisons, and diagrams of sample locations.

Chapter VI is a general abstract of the Master's thesis.

These sections conform to the style guide for research papers of the Journal of Food Science.

Chapter I

GENERAL INTRODUCTION

The primary goal of the red meat industry is to efficiently market a high quality product to the consumer. Currently, there are increased concerns relative to energy savings. The industry is searching for efficient methods which will enable it to minimize processing energy per unit of product.

Traditional methods of processing beef carcasses involve slaughtering, dressing, neck pinning, scribing, and shrouding. Typically, shrouded carcasses are stored in a drip cooler at -1C for 18 to 24 hr. Carcasses are then moved to a holding cooler (approximately 0C) for up to 48 hr (Kansas State University, 1980). After these chilling periods, the carcasses are shipped as quarters or fabricated into wholesale cuts, subprimals, or retail cuts before shipping.

One method proposed to minimize energy needs in beef processing involves conditioning the carcasses at 16C until 8 hr postmortem, then hot boning (HB) or hot processing the carcass into subprimal cuts that can then be vacuum packaged, boxed, and chilled (Kansas State University, 1980). Sides held intact from 3 to 8 hr postmortem, then fabricated, gave cuts equal to those conventionally processed when yield, color, flavor, and tenderness were evaluated (Kastner, 1972; Kastner et al.,

1973; Falk and Henrickson, 1974; Falk et al., 1975; Kastner and Russell, 1975; Kastner et al., 1976; Will et al., 1976).

Other HB techniques were performed by Schmidt and Gilbert (1970) and Schmidt and Keman (1974). Schmidt and Gilbert (1970) excised beef muscles at 2 hr postmortem. Upon excision, the muscle portions were vacuum packaged and conditioned at 15C for either 24 or 48 hr postmortem. Muscles excised prerigor and maintained at 15C for 24 or 48 hr were found to be as tender as muscles processed by conventional methods.

Schmidt and Keman (1974) hot boned muscle portions at 1 hr postmortem and stored them at about 7C for 4 hr. After 9 to 11 days of storage at 1C, taste panel and shear force data indicated no adverse affects when compared to conventionally processed samples.

An addition to the hot-boning procedures includes electrical stimulation (ES). By utilizing ES soon after slaughter, the carcass may be fabricated and chilled sooner postmortem. ES hastens the onset of rigor mortis and minimizes muscle toughening that may accompany HB and chilling performed immediately postmortem (Gilbert and Davey, 1976; Gilbert et al., 1977; Will et al., 1979).

The objective of the study outlined in Chapter III was to evaluate the feasibility of HB, ES, and a combination of ES and HB of beef carcasses, with respect to thaw and cooking losses and sensory characteristics of fresh and frozen steaks. The objective of the study outlined in Chapter IV was to compare continuous and intermittent ES with respect to postmortem pH decline rates.

Chapter II

GENERAL REVIEW OF LITERATURE

Hot Boning

Research and industry applications of hot boning (HB) or hot processing of beef carcasses have involved carcass fabrication soon (within 10 hr postmortem) after slaughter and before conventional chilling.

Advantages and Disadvantages

Hot boning offers many demonstrated and potential advantages. Kansas State University (1980) found that HB reduced: (1) cooler space requirements by 52 percent, (2) refrigeration energy input by 42 percent, (3) labor utilized in fabrication operations by 25 percent (Cross, 1979; Dvorak, 1979), and (4) in-plant residence time by 20 percent; thus reducing interest on inventory. Further reductions in labor, material, and equipment costs were noticed by Kastner (1977), Cuthbertson (1979), and Kansas State University (1980) since neck pinning, scribing, and shrouding would no longer be necessary. The maximum potential of these reductions may be realized if electrical stimulation (ES) is incorporated into the process, allowing earlier boning. Combining ES and HB will be discussed in a later section of

this chapter. McLeod et al. (1973) suggested that if lamb is hot boned and the primals are satisfactorily conditioned in boxes, mechanical handling may be facilitated. This potential advantage may also be realized by the beef industry. One of the main advantages to be derived from HB is improved yield since chilling of vacuum packaged cuts should greatly reduce evaporative losses during cooling (Dransfield, 1976; Gilbert, 1978; Cross, 1979; Cuthbertson, 1979; Dvorak, 1979; Taylor et al., 1980); and according to Cross (1979, 1980), shrink was reduced by 50 percent. In addition, Cross (1980) found that hot-boned cuts retained a better vacuum than those cuts conventionally processed. Savings in evaporative losses, due to hot boning, of up to 2 percent have been reported (Kastner, 1977; Cuthbertson, 1979; Corte et al., 1980; Taylor et al., 1980). Dransfield (1976), Cuthbertson (1979), and Gunner (1979) suggested that HB lends itself to muscle seaming techniques which may upgrade a number of cuts. HB offers possibilities in classifying muscles according to their method of cookery and their use in formulation and processing. HB also improves the water holding capacity of cuts (Gilbert, 1978), emulsion stability, color development and stability, and cure penetration which are essential factors in processed meats (Kastner, 1977; Cuthbertson, 1979).

Contrary to the advantageous factors mentioned, HB does present some potential disadvantages. One problem is the quality and yield grading of hot carcasses (Kastner, 1977; Gilbert, 1978; Cross, 1979; Dvorak, 1979). Since hot-boned carcasses would not be chilled before fabrication, new methods of grading carcasses or cuts need to be developed. Gilbert (1978) suggested that dark cutting, hot-boned beef

would be hard to identify since the ultimate pH would possibly not be reached before packaging. Possible quality control problems due to HB may include a high incidence of boning defects (Gilbert, 1978) and increased microbial counts which may result in reduced shelf life (Cross, 1979; Cross et al., 1979a). Kotula (1980) and Fung et al. (1980, 1981) indicated that it is imperative to properly chill hot-boned beef to produce a microbially acceptable product. Adequate chilling rates for hot-boned cuts that are consistent with microbial quality and product palatability have been established (Fung et al., 1981). Kastner (1977) and Cuthbertson (1979) agreed that if good hygiene was practiced at slaughter, followed by a clean HB operation, product sanitation and shelf life could be improved. Upon HB some have observed physical distortion of cuts and increased muscle toughness (McLeod et al., 1974; Gilbert, 1978; Cross, 1979; Cross et al., 1979b; Dvorak, 1979). However, distortion problems have been overcome (Cross and Tennent, 1980) and decreased tenderness does not have to be a problem (Kastner et al., 1973; Falk and Henrickson, 1974; Schmidt and Keman, 1974; Falk et al., 1975; Kastner and Russell, 1975; Kastner et al., 1976; Will et al., 1976).

Cold Shortening

Changes in muscle configuration and tenderness may be due to the phenomenon "cold shortening." Locker and Hagyard (1963) and Chrystall (1976) described the occurrence of cold shortening as the subjection of prerigor muscles (above pH 6.0) to temperatures near their freezing point. According to Marsh (1972), cold shortening starts within a few

minutes after cooling commencement, and may be complete within 1 hr. If the time span between slaughter and cold application was increased, the muscle length change progressed at a slower rate and the extent of contraction was diminished. If the delay before chilling was sufficiently long to allow formation of rigor crosslinkages, little or no shortening occurred.

The mechanisms of cold shortening were explained by Davey and Gilbert (1974). They concluded when prerigor, excised beef muscle was chilled, it underwent a slow contracture from the combined effects of mechanical and chemical events within the myofibrils. This phenomenon occurred through a 30 to 40 fold increase in the concentration of ionic calcium (Ca^{++}) in the myofibrillar region as the temperature of prerigor muscle was reduced from 15C to 0C. Chrystall (1976) stated that cold shortening occurred when prerigor muscles were chilled to temperatures below 8C before a pH of less than 6.0 was reached. Because of this cold induced contraction, one or more of the membrane components, the sarcolemma, the transverse tubular system, and the sarcoplasmic reticulum were affected. Newbold and Harris (1972) postulated that shortening can occur only while adenosine triphosphate (ATP) is present. When all ATP is depleted, rigor mortis is complete and the muscle is fixed in whatever state of contraction it happens to be in at the time. Marsh (1954) stated that the rapid rate of ATP breakdown was directly related to pH decline (lactic acid accumulation) and was an accurate measure of rigor mortis.

Marsh and Leet (1966) conducted a study to evaluate the extent of shortening on meat tenderness. They stated that a decrease in

myofibrillar length of up to 20 percent caused no toughening, but from 20 percent to approximately 40 percent shortening, the toughness drastically increased. Beyond 40 percent shortening, toughness was diminished and at 60 percent shortening, meat was sheared about as easily as that which experienced no shortening.

Tenderness

The proper application of HB can alleviate the tenderness problems associated with HB and chilling of prerigor muscle. Kastner and Russell (1975) and Kastner et al. (1976) conditioned beef sides at 16C and hot boned various muscles at 6, 8, and 10 hr postmortem. The boning times were selected because it was assumed they would minimize tenderness problems associated with HB. When the hot-boned muscles were compared with those from control sides fabricated after chilling at 2C until 48 hr postmortem, tenderness (Warner-Bratzler shear force) disadvantages were eliminated by delaying HB until 8 or 10 hr postmortem.

Other researchers have conditioned beef sides at 16C and hot boned between 2 and 8 hr postmortem (Kastner et al., 1973; Falk and Henrickson, 1974; Falk et al., 1975; Kastner and Russell, 1975; Kastner et al., 1976; Will et al., 1976). Falk and Henrickson (1974), Falk et al. (1975), and Will et al. (1976) concluded that when HB was performed at 3 hr postmortem some tenderness problems were encountered, but these tenderness problems were not practically significant. However, Kastner et al. (1973) recommended an 8 hr holding period to avoid any toughness problems, realizing that HB at 6 hr postmortem did not give greatly different results when compared to conventionally treated samples.

Schmidt and Keman (1974) hot boned muscle portions at 1 hr postmortem and immediately stored them at about 7C for 4 hr, then 1C until 24 hr postmortem. The cuts were then vacuum packaged and aged at 1C for 8 days. Shear force and taste panel evaluations indicated no significant differences between hot-boned and control muscles cooked at 9 to 11 days postmortem.

Follett et al. (1974) utilized a different method for handling prerigor cuts after HB. The semimembranosus (SM) muscles were hot boned at 1 hr postmortem, vacuum packaged, and chilled at -5C until 12 hr postmortem or chilled at 5, 10, or 15C until 24 hr postmortem before storing them at 1C until 13 days postmortem. Control SM muscles were removed at 36 hr postmortem and vacuum packaged. These muscles were chilled at 2 to 3C for 35 hr and then stored at 1C with hot-boned counterparts. Drip losses from the hot-boned, vacuum packaged cuts were less than their control counterparts. Cooking loss differences between hot-boned and control samples were small for hot-boned samples chilled at 10C. When comparisons were made between the hot-boned samples chilled at 5 to 15C and the control treatments, hot-boned usually gave equal or superior results.

Schmidt and Gilbert (1970) compared the tenderness of beef muscles removed prerigor and stored at 15C for 24 or 48 hr with the corresponding control muscles left on the carcass and chilled at 9C for 24 hr before excision. Samples from the biceps femoris (BF) and longissimus dorsi (LD) muscles stored at 15C for 24 hr were generally equal to or superior to control samples with respect to tenderness. Taste panelists found juiciness, texture, and overall acceptability

could be preserved upon storage of vacuum packaged muscles for 48 hr at 15C. The SM showed no undesirable treatment effects; however, the hot-boned semitendinosus (ST) muscles conditioned at 15C for either 24 or 48 hr had significantly larger Warner-Bratzler shear force values than their controls. ST shear results were not supported by taste panel evaluations.

Dransfield et al. (1976) hot boned beef sides within 3 hr postmortem. After excision of various muscles, they were vacuum packaged, conditioned at 10C for 24 hr, and chilled at 1C until 6 to 10 days. This treatment was compared with samples from sides conditioned at ambient temperatures for 5 hr, then fabricated at 24 hr postmortem. Control samples were aged at 1C for 1 to 5 days postmortem. The overall tenderness mean for hot-boned samples was found to be slightly tougher than controls; however, the authors noted this to be negligible even though the overall mean difference was statistically significant ($P < .001$). This statistical difference in overall tenderness was attributed to the psoas major (PM) muscle which increased in toughness. The authors concluded that this toughening of the PM was due to prerigor excision.

The previous successful HB practices do not necessarily facilitate continuous product flow because of the conditioning and/or aging periods required. However, by utilizing ES which speeds rigor onset (Will et al., 1979), carcasses may be hot boned and resultant cuts packaged and chilled in a more continuous fashion (Gilbert and Davey, 1976; Gilbert et al., 1977; Seideman et al., 1979).

Electrical Stimulation

The use of ES for increasing meat tenderness is not a new idea; its use for this purpose was first suggested by Benjamin Franklin in 1749 (Lopez and Herbert, 1975). It was observed that killing turkeys electrically made the muscle exceptionally tender. Although this was the first report of ES, further use of ES was two centuries away. Harsham and Deatherage (1951) obtained the first patent for electrically stimulated beef. They found that electrical stimulation of beef carcasses as soon as possible after slaughter accelerated postmortem pH decline and the onset of rigor, with the apparent additional advantage of tenderizing the meat.

Overview of Effects

Savell et al. (undated) studied industrial applications of ES. They stated that when the sequence of slaughter was too rapid and beef was chilled too rapidly, "heat ring" formation became a problem. "Heat ring" as described by Savell et al. (undated) was slightly dark, coarse, depressed lean (in the LD muscle, as exposed upon ribbing) extending inward about 1.27 to 2.54 cm from the subcutaneous side of the loineye. This problem can delay federal grading. The problem is noticed primarily in leaner cattle with a limited amount of outside fat cover. "Heat ring" results from a slowed rate of postmortem glycolysis near the muscle surface caused by rapid chilling. The surface pH of the muscle remains relatively high and a dark color results. As the pH drops (or postmortem glycolysis nears completion) the color becomes

brighter (Savell et al., undated). "Heat ring" can be avoided by using ES since it is known to increase the rate of postmortem glycolysis (Savell et al., undated; Davey et al., 1976; McCollum and Henrickson, 1977; Cross et al., 1979b; Will et al., 1979). Savell et al. (undated) found that ES resulted in a faster "setting-up" of the intramuscular fat of the beef ribeye, caused by improved firmness of the muscle.

Cross et al. (1979b) and McKeith et al. (1980) concluded that ES, irrespective of beef carcass sex or maturity, improved lean maturity score, lean color score, and decreased shear force values. The results obtained by Hall et al. (1980) agreed with the findings of McKeith et al. (1980) and conclusions were drawn that ES decreased surface discoloration and enhanced overall appearance of retail cuts. This benefit coupled with electrical stimulation's demonstrated effectiveness in increasing the tenderness of some muscles makes ES a unique process.

Bendall and Rhodes (1976) postulated that if postmortem pH decline was too rapid and if the pH values fell below 6.0 within 1.5 hr of slaughter while the deep musculature temperatures are above 35C, the pale, soft, and exudative (PSE) condition could occur. They encountered no excessive drip loss or evidence of PSE in electrically stimulated carcasses.

ES caused an increase in tenderness by preventing muscle toughening associated with cold shortening (Carse, 1973; Chrystall and Hagyard, 1975, 1976; Bendall et al., 1976; Davey et al., 1976; Bouton et al., 1978; Bouton et al., 1980a,b; George et al., 1980).

According to Chrystall and Hagyard (1975), ES accelerated lamb conditioning and reduced the required 18 to 24 hr postmortem holding

time prior to freezing needed to avoid cold induced toughening. Aging may occur at an accelerated rate for those carcasses that enter rigor mortis at an elevated temperature.

Bendall and Rhodes (1976) and Gilbert (1978) concluded that by utilizing ES, cooling and freezing beef muscles to deep tissue temperatures of 8 to 10C can be started much sooner postmortem than normal, and the detrimental effects of cold shortening are minimal. The amount of cold shortening in electrically stimulated muscle may be estimated by measuring sarcomere lengths. From the studies conducted by Smith et al. (1977, 1979); Savell et al. (1977, 1979); McKeith et al. (1980); Seideman et al. (1979); Will et al. (1979); and George et al. (1980), no differences in sarcomere lengths of electrically stimulated versus non-stimulated muscle were observed. However, differences in lengths of the contractile units have occasionally been noticed in stimulated as opposed to non-stimulated muscle (Smith et al., 1977, 1979; Bouton et al., 1980a; George et al., 1980).

According to Dutson et al. (1980b), under normal chilling conditions, reduction of cold shortening is not a factor in the tenderness improvement generated by ES.

Another possible mechanism for the increased tenderness in electrically stimulated meat is accelerating proteolysis. Studies by Locker and Daines (1976) and Dutson et al. (1977, 1980a,b) have shown that conditions which favor proteolysis, such as acid pH and high muscle temperature, are associated with tenderizing meat. Dutson et al. (1980a) electrically stimulated the left side of 6 lamb carcasses and the right sides served as the non-stimulated controls.

Samples were removed 1 hr postmortem and assayed for total, free, and specific activities of the lysosomal enzymes, β-glucuronidase, and cathepsin-C. An increase ($P < .05$) in percent free activity (24 to 30 percent) of both enzymes was found in the samples from stimulated carcasses. This indicated that lysosomal membranes are disrupted due to ES. Another possible explanation of the increased tenderness of the stimulated samples is the increased rate of enzyme release from the lysosomes (low pH, high temperature) which is conducive to greater activity. This increase in lysosomal enzyme release under ideal conditions could cause hydrolysis of the myofibrillar proteins and possible hydrolysis of the connective tissue proteins.

Research reported by Savell et al. (1978a) demonstrated that structural alterations do occur in electrically stimulated muscles. The alterations were first noted as "physical disruptions." After viewing the muscle samples through light and electron microscopes, the disruptions appeared as contracture bands or contracture nodes. Electron micrographs showed that electrically stimulated samples had less well defined I bands and Z lines throughout the contracture bands, while sarcomeres on either side of the contracture band were stretched. These results suggest the tenderness improvement associated with the use of ES can be achieved by means other than the prevention of cold shortening or accelerated aging.

The most recent explanation of the ES tenderness mechanism was reported by Judge et al. (1980). Their research examined the possibility that ES might alter the thermal stability of collagen. This change could provide some insight concerning the relative importance

of collagen stability to tenderness and explain the basis of some of the tenderization produced by ES. Thermal shrinkage temperature (Ts) was measured by a differential scanning calorimeter. Electrical stimulation at 45 min postmortem with 20 pulses of 2 sec duration with 1 sec between pulses, 480 volts (V), 60 cycles/sec, and 3.5 initial amperes (A) of alternating current (AC) lowered Ts of the perimysial collagen. These authors suggested that since ES reduced the heat stability of collagen, the possibility of an electrically stimulated induced breakage or destruction of the collagen crosslinks seemed feasible.

pH Decline and Sensory Effects

Muscle pH decline is a measure of postmortem glycolysis and the onset of rigor mortis (Marsh, 1954). Once muscle is below pH 6.0, cold shortening is unlikely to occur (Bendall and Rhodes, 1976). ES is capable of accelerating postmortem pH decline and hastening rigor development (Carse, 1973; Davey et al., 1976).

It was the consensus of Grusby et al. (1976), Taylor and Marshall (1980), and George et al. (1980) that ES increased the rate of pH decline and tenderness in the LD muscle. Even though George et al. (1980) stimulated beef carcasses at 1 hr postmortem with 700 V, 25 pulses per sec for 2 min, and reversed the electrode polarity every 30 sec, the ST muscle did not react the same as the LD. The ES ST reached pH 6.0 at 2.1 hr postmortem as compared with 7.1 hr postmortem for the non-stimulated control; whereas, the ES LD reached pH 6.0 at

1.5 hr postmortem and the non-stimulated control at 5.9 hr postmortem. The ST was also found to be less tender than the LD.

Bendall (1976) studied electrical stimulation of rabbit and lamb carcasses 15 min postmortem with 250 V, 0.8 A, and a sinusoidal pulse of rates between 1 and 20 hertz (Hz). The result was that pH 6.0 was obtained in 1.5 hr postmortem. At approximately pH 6.0 or 50 percent ATP disappearance, cooling or freezing stimulated lamb carcasses to below 10C was performed without the detrimental effect of cold induced muscle toughening. Bendall et al. (1976), Bendall and Rhodes (1976), and Bendall (1979) used essentially the same stimulation parameters on beef carcasses (700 V, 6 A, AC), except for the frequency (15 to 25 Hz) and stimulation time (40 to 50 min postmortem). Using this frequency for 2 min dropped the pH of the forelimb, back, and leg muscles to 6.0 within 1 hr postmortem.

Carse (1973) electrically stimulated lamb carcasses at 30 to 40 min postmortem and continued the stimulation for 30 min. The carcasses were subjected to direct current (DC) square wave pulses (2 to 13.5 msec duration) at 0 to 250 V delivered at rates from 3 to 17.5 per sec. At 3.0 hr postmortem pH 6.0 was reached in the LD, SM, BF, and gluteus medius (GM) muscles. The treated sides were conditioned at 18C for 5 hr postmortem and then frozen at -18C. Shear force evaluations showed that electrically stimulated samples were significantly more tender than the controls. Carse (1973) concluded that ES before freezing can cause a significant reduction in muscle toughening.

Along with Carse (1973) were other New Zealand researchers who proposed various methods of ES to improve the tenderness of meat

(Chrystall and Hagyard, 1976; Davey et al., 1976; Devine, 1976). Chrystall and Hagyard (1976) stimulated lamb carcasses within 5 min of slaughter for 55 sec with sinusoidal pulses (5 msec duration, 15 Hz, 3600 V) and the polarity was changed with successive pulses. The carcasses were then frozen 60 min postmortem at -18C. LD tenderness was tested with a tenderometer. Stimulated samples were found to have a faster pH decline and were more tender than their control counterparts which were immediately frozen at -18C. LD pH in the stimulated carcasses fell to below 6.0 within 1 hr postmortem, compared with the 14 hr required by unstimulated muscle.

According to Devine (1976), pH decline is not the only factor that influences the rate of rigor mortis onset. The rate of postmortem glycolysis will tend to be higher in muscles which have higher internal temperatures and cool at slower rates (Lawrie, 1979). Devine (1976) noticed that after stimulating beef carcasses from 10 min to 3 hr postmortem with 50 Hz AC, 150 to 190 V, 0.45 A continuously or intermittently for 3 min the temperature of the sternomandibularis muscle rose 3C. He found that stimulated muscle pH reached 6.0 in 3.5 hr postmortem; however, neither continuous or intermittent stimulation altered the rate of postmortem pH decline. Devine (1976) attributed the increased muscle tenderness not only to a rapid pH decline, but also to aging which commences at higher body temperatures.

Shaw and Walker (1977) and Deatherage (1980) studied the effect of low voltage ES on beef and rabbit carcasses, respectively. Both researchers concluded that voltages in the range of 110 to 115 V, (AC or DC) were successful in lowering the pH of various muscles. Shaw

and Walker (1977) found noticeable pH differences at 1, 4, and 24 hr when carcasses were stimulated approximately 35 min postmortem with 110 V and pulsed with DC (40 pulses per sec, pulse width 2 msec) compared to non-stimulated counterparts. Shaw and Walker (1977) concluded that their methodology of ES would help prevent muscle toughening due to cold shortening.

Much of the research in the United States on the effects of ES tenderization has been summarized by Savell et al. (undated), Dutson et al. (1977, 1980a,b), Savell et al. (1977, 1978a,b,c, 1979), Smith et al. (1977, 1979), and McKeith et al. (1980). These Texas A&M researchers concluded that electrical stimulation of beef, lamb, and goat carcasses at 1 hr postmortem with 110 or 440 V of pulsed (25 impulses of 0.5 to 1 sec duration) AC, 5 A, and 50 to 60 cycles per sec increased the rate of postmortem pH decline in the LD muscle over the range of 2 to 11 hr postmortem when compared with non-stimulated counterparts. Their results demonstrated that ES increased cooked loin steak tenderness by 12 to 55 percent, enhanced overall palatability ratings when evaluated by a trained taste panel, and decreased Warner-Bratzler shear force values.

McCollum and Henrickson (1977) and Raccach and Henrickson (1979) stimulated beef carcasses at 30 min postmortem for a duration of 15 min with DC square wave pulses of 300 V, 400 cycles per sec with a duration of 0.5 msec, and a current of 1.7 A. These researchers concluded that postmortem glycolytic rates could be optimized when these parameter levels were used. McCollum and Henrickson (1977) studied correlations between tenderness and increasing the duration

of stimulation. They concluded that the shortest stimulation period used (1 min) was adequate to set the LD and SM muscles into rigor and prevent muscle toughening due to cold shortening. At 2 hr postmortem the authors found that the stimulated LD pH was 5.3 as compared with 6.4 for the non-stimulated controls. The stimulated SM reached pH 6.0 in 2 hr; whereas, the non-stimulated control was at pH 6.5.

Demeyer et al. (1980) slaughtered 7 bulls and stimulated one side of each at 45 min postmortem with 200 to 300 V, 50 Hz DC (pulse width of 10 msec). LD and ST muscle pH was about 0.6 units lower than the control non-stimulated counterparts at 25 min after stimulation. Low voltage stimulation (1) increased the rate of pH decline so that pH 6.0 was reached within 2 hr after stunning, (2) an evenly distributed overall tenderizing effect of approximately 6 percent was obtained by ES and 1 week of cooler aging, and (3) improvements in Warner-Bratzler shear force values did not seem to be evenly distributed over the muscles sampled.

ES offers a number of benefits to the red meat packing and processing industry as explained in the previous literature; however, the optimal parameter combination(s) of continuous or intermittent stimulation, postmortem stimulation time, duration of stimulation, frequency (Hz), amperage (A), voltage (V), alternating current (AC) or direct current (DC) have not been elucidated and need further investigation.

Electrical Stimulation and Hot Boning

Considering the previously mentioned economic aspects of HB and the mechanisms by which ES minimizes the detrimental effects of prerigor excision and early chilling or freezing, researchers have combined the two treatments to evaluate their use in the red meat industry.

ES and HB of beef carcasses were studied by Gilbert and Davey (1976). Six steers were exsanguinated and split into sides. At 30 min postmortem the right sides were stimulated with 3600 V, 2 A, and a frequency of 15 Hz (sinusoidal pulses) for a 2 min duration. After stimulation, both sides were transferred to the coolers and temperatures of the LD and SM muscles were monitored. In 5 hr the LD and SM temperatures had fallen to approximately 20C and 35C respectively and in 24 hr had further declined to 4C and 11C, representing a rapid chill. HB was initiated at 5 hr postmortem for the stimulated sides. The LD, SM, BF, GM, and PM muscles were excised, halved, and vacuum packaged. One of the halves of each muscle was immediately frozen and stored at -18C and the second group was aged for 72 hr at 10C before freezing. Muscle pH measurements were taken at 5 and 24 hr postmortem. Values for the BF, SM, PM, and LD had reached ultimate pH in 5 hr postmortem. From these determinations, all muscles were in rigor at 5 hr and could be boned safely without the risk of prerigor excision and cold shortening as a result of the rapid chilling and freezing processes. Taste panel evaluations determined that samples from stimulated sides boned at 5 hr were more tender than those from unstimulated sides. Subjective evaluations showed that tenderness of samples from stimulated carcasses

boned at 5 hr and frozen were as good as unstimulated counterparts chilled for 24 hr. These authors concluded that HB and freezing after ES does not affect eating quality; moreover, ES permitted additional tenderizing through aging.

Gilbert et al. (1977) stimulated beef carcasses with the same methodology as did Gilbert and Davey (1976); however, boning was performed at 1 hr and 24 hr postmortem. Electrically stimulated strip loin and inside rounds were divided into two groups. The first group was conditioned at 5C and aged for 46 hr before freezing (-35C) while the other group was immediately frozen. The control side was chilled to 8C in 24 hr before muscle excision. The cuts were either aged for 65 hr at 10C, then frozen (-35C) or directly frozen at the same temperature. Tenderness was evaluated by a trained taste panel and a tenderometer. Results showed unstimulated, unaged cuts were all tougher than their stimulated counterparts with the exception of the PM. Gilbert et al. (1977) explained that electrically stimulated and hot-boned (ESHB) cuts aged at 5C for 46 hr before freezing attained a higher, more uniform degree of tenderness than unaged, frozen cuts. The advantage of these methods is that ES followed by HB reduces the chilling and aging period to 2 days where conventionally it takes 10 to 20 days.

Seideman et al. (1979) removed sections of LD and SM muscles from beef sides that had been electrically stimulated at 1 hr postmortem and from conventionally handled sides at 24 hr. At 30 to 40 min postmortem the sides designated to be electrically stimulated received 25 pulses of 0.5 to 1 sec duration, 400 V (AC), 5 A, and 50 to 60 cycles per sec.

These muscles were vacuum packaged and aged for 2 weeks at 1C. Evaluations of ESHB beef indicated no detrimental effects on tenderness and flavor. The ESHB beef was as palatable as conventionally processed beef if the sides were electrically stimulated before boning and if the meat was vacuum packaged and aged for 2 weeks at 1C.

ES and HB were investigated by Will et al. (1979). The effectiveness of ES as a means of speeding postmortem muscle metabolism as measured by ATP depletion and sarcomere length was observed. At 30 min postmortem, stimulated sides received a DC square wave pulse of 300 V. The frequency of the stimulus was 400 cycles per sec with a duration of 0.5 msec and a current of 1.9 A which was applied to the side for 15 min. After stimulation, the sides were stored at 16C. HB was initiated at 2 hr postmortem, then the muscles were chilled at 1C for 46 hr. Tenderness, as evaluated by Warner-Bratzler shear force and taste panel values, was improved in the ESHB beef, but sarcomere lengths were not different between the control sides which were stored at 16C for 2 hr postmortem then at 1C for 46 hr before being fabricated.

Nichols and Cross (1980) studied the combined effects of ES and HB on pH decline and sarcomere length of LD and SM muscles. Eighty sides were stimulated, hot boned at 1, 2, or 4 hr postmortem, and muscles were stored immediately after excision at -30C, or were chilled 6 hr at 3C then frozen at -30C or were chilled at 3C for 5 days before freezing (-30C). Control sides were chilled 48 hr before the LD and SM were excised. The designated sides for ES were stimulated 1 hr postmortem with 60 Hz (AC) of continuous stimulation for 2 min. Current was applied in terms of constant amperage, so voltage ranged from 140 to

200 V. Excision time and ES had significant ($P < .0001$) effects on pH decline. Compared with -30C storage, a 3C storage temperature resulted in an even faster decline in pH in electrically stimulated muscle. Mean values for initial and final sarcomere lengths of the LD were not affected by ES or HB.

Cross and Tennent (1980) studied accelerated processing systems by electrically stimulating and hot boning 72 beef sides. Sides were stimulated with 1.5 A of 150 to 400 V of alternating current (60 Hz) for 3 min with four (10 sec duration) shocks per min and afterwards were hot boned at 1, 4, or 48 hr postmortem. Muscles boned at 48 hr were more tender than muscles boned at 1 or 4 hr postmortem. ES tended to reduce the negative effects of excision time on tenderness; however, muscles frozen immediately (-40C) or before 24 hr were borderline in tenderness. Even though stimulation contributed to the increased tenderness of the LD, the increase was not enough to equal ESHB LD muscles that were aged 20 days then frozen at -40C. Cross and Tennent (1980) concluded that freezing muscle immediately would involve some tenderness risk even with ES.

Kastner et al. (1980) electrically stimulated and hot boned the LD, SM, PM, and triceps brachii, long head (TB). Sides to be electrically stimulated were treated with a continuous, 2 min stimulation of 400 to 600 V, approximately 1 A, and 60 Hz of AC at 1 hr postmortem and hot boned at 2 hr postmortem. Muscles were aged until 6 days postmortem. Color, pH decline, temperature, and tenderness were monitored. The stimulation parameters used were effective in increasing the rate of pH decline in the ESHB muscles as compared with the control and

hot-boned counterparts. No differences were observed between the control and ESHB Warner-Bratzler shear force values of the LD. On the contrary, the ESHB SM shear force values were larger than the control counterparts. These results were supported by taste panel evaluations. When TB Warner-Bratzler shear force treatment means were compared, no differences were found. However, when PM controls were compared with their treated counterparts, larger ($P < 0.05$) shear force values for the control were observed, but when comparisons were made between the hot-boned and ESHB treatments no statistical differences were found. No statistical differences were observed between control and ESHB muscles with regard to color; nevertheless, the polyvinyl chloride (PVC) overwrapped ESHB samples appeared slightly brighter each day of display. Kastner et al. (1980) concluded that ES may not be necessary to successfully hot bone some muscles, but it may be needed particularly if conditioning periods are not used.

Taylor et al. (1980) electrically stimulated and hot boned sides at 50 min and 1 to 2 hr postmortem, respectively. The stimulation application consisted of 700 V at 25 pulses per sec for four 30 sec periods. When ESHB muscles were rapidly chilled at -1C until 24 hr postmortem, more drip loss and lack of color uniformity were noticed for muscles from sides that were conditioned at 15C for 7 hr before being chilled at 0 to 1C, then boned at 48 hr postmortem. This suggests that the rapid pH decline increased protein denaturation. Taste panel evaluations determined that ES lended no additional tenderization to the hot-boned muscle samples.

Zebu cattle were used in an ESHB experiment conducted by Corte et al. (1980). The sides were stimulated (700 V, intermittent AC, 60 Hz, 2 min duration) 30 min after exsanguination and hot boned at 45 min postmortem. The boned cuts were either chilled 2 hr after slaughter at 2C for 5 days or were frozen 2 hr postmortem at -40C and stored at -20C for 3 months. The initial pH values for the LD and SM muscles were between 6.75 and 6.85. In the ESHB cuts, the muscle pH reached 6.1 to 6.2 in 1.0 to 1.5 hr after bleeding as compared with 8 hr to reach pH 6.0 for non-stimulated controls. Warner-Bratzler shear force values and palatability ratings showed LD muscles from the ESHB treatment both chilled and frozen to be acceptable in tenderness when compared with their control counterparts. However, only the chilled ESHB SM steaks were significantly more tender than the controls.

HB soon postmortem appears to be an economical process and can give a product equal or superior to that conventionally processed. ES has generally been shown to aid the hot-boning technique and does not produce detrimental effects. However, the various applications of ESHB needed to support variations in centralized processing warrant additional investigation.

REFERENCES

Bendall, J.R. 1976. Electrical stimulation of rabbit and lamb carcasses. J. Sci. Fd. Agric. 27:819.

Bendall, J.R., Ketteridge, C.C., and George, A.R. 1976. The electrical stimulation of beef carcasses. J. Sci. Fd. Agric. 27:1123.

Bendall, J.R. and Rhodes, D.N. 1976. Electrical stimulation of the beef carcass and its practical application. Proceedings of 22nd Meat Res. Conf. Vol. I. Sweden.

Bendall, J.R. 1979. Ways of modifying the post-mortem changes in skeletal muscle. J. Sci. Fd. Agric. 30:1104.

Bouton, P.E., Ford, A.L., Harris, P.V., and Shaw, F.D. 1978. Effect of low voltage stimulation of beef carcasses on muscle tenderness and pH. J. Food Sci. 43:1392.

Bouton, P.E., Ford, A.L., Harris, P.V., and Shaw, F.D. 1980a. Electrical stimulation of beef sides. Meat Sci. 4:145.

Bouton, P.E., Shaw, F.D., and Harris, P.V. 1980b. Electrical stimulation of beef carcasses in Australia. Proceedings of 26th European Meeting of Meat Research Workers. Colorado Springs, Colorado. 2:23.

Carse, W.A. 1973. Meat quality and the acceleration of postmortem glycolysis by electrical stimulation. J. Food Technol. 8:163.

Chrystall, B.B. and Hagyard, C.J. 1975. Accelerated conditioning of lamb. N.Z. J. Agric. Res. June:7.

Chrystall, B.B. and Hagyard, C.J. 1976. Electrical stimulation and lamb tenderness. N.Z. J. Agric. Res. 19:7.

Chrystall, B.B. 1976. Accelerated conditioning of meat. MIRINZ. Meat Technol. Proceedings of 18th Meat Ind. Res. Conf. Hamilton, New Zealand. 5.

Corte, O.O., Cia, G., Picchi, V., Procknor, M.L.S.C., and Delazari, I. 1980. Electrical stimulation and hot boning of beef carcasses associated with chilling or freezing. Proceedings of 26th European Meeting of Meat Research Workers. Colorado Springs, Colorado. 2:53.

Cross, H.R. 1979. Pre-rigor meats in fresh sausage. Proceedings of 21st Annual Meat Science Institute. Athens, Georgia. 23.

Cross, H.R., Berry, B.W., and Muse, D. 1979a. Sensory and cooking properties of ground beef prepared from hot and chilled beef carcasses. J. Food Sci. 44:1432.

Cross, H.R., Smith, G.C., Kotula, A.W., and Muse, D.A. 1979b. Effects of electrical stimulation and shrouding method on quality and palatability of beef carcasses. J. Food Sci. 44:1560.

Cross, H.R. 1980. Optimal systems for rapid processing of beef. Proceedings of 26th European Meeting of Meat Research Workers. Colorado Springs, Colorado. 2:15.

Cross, H.R. and Tennent, I. 1980. Accelerated processing systems for USDA Choice and Good beef carcasses. J. Food Sci. 45:765.

Cuthbertson, A. 1979. Hot processing of meat: a review of the rationale and economic implications. Meat and Livestock Commission, Bletchley, Milton Keynes, United Kingdom.

Davey, C.L. and Gilbert, K.V. 1974. The mechanism of cold-induced shortening in beef muscle. J. Food Technol. 9:51.

Davey, C.L., Gilbert, K.V., and Carse, W.A. 1976. Carcass electrical stimulation to prevent cold shortening toughness in beef. N.Z. J. Agric. Res. 19:13.

Deatherage, F.E. 1980. Early investigations on the acceleration of post-mortem tenderization of meat by electrical stimulation. Proceedings of 26th European Meeting of Meat Research Workers. Colorado Springs, Colorado. 2:2.

Demeyer, D., Vandenriessche, F., Verbeke, R., and Vandevoorde, G. 1980. Low voltage electrical stimulations of beef carcasses: distribution of tenderizing effect in the carcass and relation to changes in sarcomere length. Proceedings of 26th European Meeting of Meat Research Workers. Colorado Springs, Colorado. 2:6.

Devine, C.E. 1976. Accelerated conditioning of meat. Proceedings of 18th Meat Ind. Res. Conf. MIRINZ. Hamilton, New Zealand. 10.

Dransfield, E., Brown, A.J., and Rhodes, D.N. 1976. Eating quality of hot deboned beef. J. Food Technol. 11:401.

Dutson, T.R., Yates, L.D., Smith, G.C., Carpenter, Z.L., and Hostetler, R.L. 1977. Rigor onset before chilling. Proc. Recip. Meat Conf. 30:79.

Dutson, T.R., Smith, G.C., and Carpenter, Z.L. 1980a. Lysosomal enzyme distribution in electrically stimulated ovine muscle. J. Food Sci. 45:1097.

Dutson, T.R., Smith, G.C., Savell, J.W., and Carpenter, Z.L. 1980b. Possible mechanisms by which electrical stimulation improves meat tenderness. Proceedings of 26th European Meeting of Meat Research Workers. Colorado Springs, Colorado. 2:84.

Dvorak, N. 1979. On-rail hot beef boning: an idea whose time has come. Proceedings of 21st Annual Meat Science Institute. Athens, Georgia. 45.

Falk, S.N. and Henrickson, R.L. 1974. Feasibility of hot boning the bovine carcass. Animal Science Research. Oklahoma Agric. Exp. Station. 145.

Falk, S.N., Henrickson, R.L., and Morrison, R.D. 1975. Effect of boning beef carcasses prior to chilling on meat tenderness. J. Food Sci. 40:1075.

Follett, M.R., Norman, G.A., and Ratcliff, P.W. 1974. The ante-rigor excision and air cooling of beef semimembranosus muscles at temperatures between -5C and +15C. J. Food Technol. 9:509.

Fung, D.Y.C., Kastner, C.L., Lee, C., Hunt, M.C., Dikeman, M.E., and Kropf, D.H. 1980. Recent developments in microbiological studies on hot-boned beef. Presented at the International Symposium on Recent Advances in Food Science and Technology. January, 1980. Taipei, Republic of China.

Fung, D.Y.C., Kastner, C.L., Lee, C-Y, Hunt, M.C., Dikeman, M.E., and Kropf, D.H. 1981. Initial chilling rate effects on bacterial growth of hot-boned beef. J. Food Prot. In Press.

George, A.R., Bendall, J.R., and Jones, C.D. 1980. The tenderizing effect of electrical stimulation of beef carcasses. Meat Sci. 4:51.

Gilbert, K.V. and Davey, C.L. 1976. Carcass electrical stimulation and early boning of beef. N.Z. J. Agric. Res. 19:429.

Gilbert, K.V., Davey, C.L., and Newton, K.G. 1977. Electrical stimulation and the hot boning of beef. N.Z. J. Agric. Res. 20:139.

Gilbert, K.V. 1978. The processing of accelerated conditioned beef. Proceedings of 20th Meat Ind. Res. Conf. Hamilton, New Zealand. 26.

Grusby, A.H., West, R.L., Carpenter, J.W., and Palmer, A.Z. 1976. Effects of electrical stimulation on tenderness. J. Anim. Sci. 42:253.

Gunner, D.B. 1979. Commercial implications of electrical stimulation and hot boning. J. Sci. Food Agric. 30:1106.

Hall, L.C., Savell, J.W., and Smith, G.C. 1980. Retail appearance of electrically stimulated beef. J. Food Sci. 45:171.

Harsham, A. and Deatherage, F.E. 1951. U.S. Patent 2544681.

Judge, M.D., Reeves, E.S., and Aberle, E.D. 1980. Effect of electrical stimulation on thermal shrinkage temperature of bovine muscle collagen. Proceedings of 26th European Meeting of Meat Research Workers. Colorado Springs, Colorado. 2:74.

Kansas State University. 1980. Economic feasibility of hot processing beef carcasses. Kansas Agric. Exp. Station Bulletin. Bulletin 639. December, 1980.

Kastner, C.L. 1972. Influence of "hot" boning on bovine muscle. Oklahoma State University. Ph.D. dissertation.

Kastner, C.L., Henrickson, R.L., and Morrison, R.D. 1973. Characteristics of hot-boned bovine muscle. J. Anim. Sci. 36:484.

Kastner, C.L. and Russell, T.S. 1975. Characteristics of conventionally and hot-boned bovine muscle excised at various conditioning periods. J. Food Sci. 40:747.

Kastner, C.L., Sullivan, D.P., Ayaz, M., and Russell, T.S. 1976. Further evaluation of conventional and hot-boned bovine longissimus dorsi muscle excised at various conditioning periods. J. Food Sci. 41:97.

Kastner, C.L. 1977. Hot processing: update on potential energy and related economies. Proceedings of Meat Ind. Res. Conf. American Meat Institute Foundation. Arlington, Virginia. 43.

Kastner, C.L., Dikeman, M.E., Nagele, K.N., Lyon, M., Hunt, M.C., and Kropf, D.H. 1980. Effects of carcass electrical stimulation and hot boning on selected beef muscles. Proceedings of 26th European Meeting of Meat Research Workers. Colorado Springs, Colorado. 2:40.

Kotula, A.W. 1980. Bacteria associated with electrically stimulated and hot-boned meat. Proceedings of 26th European Meeting of Meat Research Workers. Colorado Springs, Colorado. 2:66.

Lawrie, R.A. 1979. "Meat Science," p. 93, Pergamon Press, Oxford.

Locker, R.H. and Hagyard, C.J. 1963. A cold shortening effect in beef muscles. J. Sci. Fd. Agric. 14:787.

Locker, R.H. and Daines, G.J. 1976. Tenderness in relation to the temperature of rigor onset in cold shortened beef. J. Sci. Fd. Agric. 27:193.

Lopez, C.A. and Herbert, E.W. 1975. "The Private Franklin, The Man and His Family," 1st Ed. p. 44. W.W. Norton and Co., Inc., New York.

Marsh, B.B. 1954. Rigor mortis in beef. J. Sci. Fd. Agric. 5:70.

Marsh, B.B. and Leet, N.G. 1966. Studies in meat tenderness III: the effects of cold shortening on tenderness. J. Food Sci. 31:450.

Marsh, B.B. 1972. Post-mortem muscle shortening and meat tenderness. Presented at 1972 Meat Ind. Res. Conf. 109.

McCollum, P.D. and Henrickson, R.L. 1977. The effect of electrical stimulation on the rate of post-mortem glycolysis on some bovine muscles. J. Food Qual. 1:15.

McKeith, F.K., Smith, G.C., Savell, J.W., Dutson, T.R., Carpenter, Z.L., and Hammons, D.R. 1980. Electrical stimulation of mature cow carcasses. J. Anim. Sci. 50:694.

McLeod, K., Gilbert, K.V., Wyborn, R., Wenham, L.J., Davey, C.L., and Locker, R.H. 1973. Hot cutting of lamb and mutton. J. Food Technol. 8:71.

McLeod, K., Gilbert, K.V., Fairbarn, S.J., and Locker, R.H. 1974. Further experiments on the hot-cutting of lamb. J. Food Technol. 9:179.

Newbold, R.P. and Harris, P.V. 1972. The effect of pre-rigor changes on meat tenderness. J. Food Sci. 37:337.

Nichols, J.E. and Cross, H.R. 1980. Effects of electrical stimulation and early postmortem muscle excision on pH decline, sarcomere length and color in beef muscles. J. Food Prot. 43:514.

Raccach, M. and Henrickson, R.L. 1979. The combined effect of electrical stimulation and blade tenderization on some bovine muscles. J. Food Processing and Preservation. 3:43.

Savell, J.W., Smith, G.C., Dutson, T.R., and Carpenter, Z.L. undated. Tenderizing beef with electricity. Fact Sheet. Texas Agric. Ext. Service. Texas A&M University. College Station, Texas. 1.

Savell, J.W., Smith, G.C., Dutson, T.R., Carpenter, Z.L., and Suter, D.A. 1977. Effect of electrical stimulation on palatability of beef, lamb and goat meat. J. Food Sci. 42:702.

Savell, J.W., Dutson, T.R., Smith, G.C., and Carpenter, Z.L. 1978a. Structural changes in electrically stimulated beef muscle. J. Food Sci. 43:1606.

Savell, J.W., Smith, G.C., and Carpenter, Z.L. 1978b. Beef quality and palatability as affected by electrical stimulation and cooler aging. J. Food Sci. 43:1666.

Savell, J.W., Smith, G.C., and Carpenter, Z.L. 1978c. Effect of electrical stimulation on quality and palatability of light-weight beef carcasses. J. Anim. Sci. 46:1221.

Savell, J.W., Smith, G.C., Carpenter, Z.L., and Parrish, F.C., Jr. 1979. Influence of electrical stimulation on certain characteristics of heavy-weight beef carcasses. J. Food Sci. 44:911.

Schmidt, G.R. and Gilbert, K.V. 1970. The effect of muscle excision before the onset of rigor mortis on the palatability of beef. J. Food Technol. 5:331.

Schmidt, G.R. and Keman, S. 1974. Hot boning and vacuum packaging of eight major bovine muscles. J. Food Sci. 39:140.

Seideman, S.C., Smith, G.C., Dutson, T.R., and Carpenter, Z.L. 1979. Physical, chemical and palatability traits of electrically stimulated, hot-boned, vacuum-packaged beef. J. Food Prot. 42:651.

Shaw, F.D. and Walker, D.J. 1977. Effect of low voltage stimulation on beef carcasses on muscle pH. J. Food Sci. 42:1140.

Smith, G.C., Dutson, T.R., Carpenter, Z.L., and Hostetler, R.L. 1977. Using electrical stimulation to tenderize meat. Proceedings of 19th Meat Ind. Res. Conf. American Meat Institute Foundation. Arlington, Virginia. 147.

Smith, G.C., Dutson, T.R., Cross, H.R., and Carpenter, Z.L. 1979. Electrical stimulation of hide-on and hide-off calf carcasses. J. Food Sci. 44:335.

Taylor, A.A., Shaw, B.G., and MacDougall, D.B. 1980. Hot deboning beef with and without electrical stimulation. Proceedings of 26th European Meeting of Meat Research Workers. Colorado Springs, Colorado. 2:45.

Taylor, D.G. and Marshall, A.R. 1980. Low voltage electrical stimulation of beef carcasses. J. Food Sci. 45:144.

Will, P.A., Henrickson, R.L., and Morrison, R.D. 1976. The influence of delay chilling and hot boning on tenderness of bovine muscle. J. Food Sci. 41:1102.

Will, P.A., Henrickson, R.L., Morrison, R.D., and Odell, G.V. 1979. Effect of electrical stimulation on ATP depletion and sarcomere length in delay-chilled bovine muscle. J. Food Sci. 44:1646.

Chapter III

EFFECTS OF BEEF CARCASS ELECTRICAL STIMULATION AND HOT BONING ON SENSORY CHARACTERISTICS AND THAW AND COOKING LOSSES OF FRESH AND FROZEN STEAKS

ABSTRACT

Ninety-six sides from 48 U.S.D.A. Good and Choice grade carcasses were used to study the effects of hot boning (HB), electrical stimulation (ES), a combination of electrical stimulation and hot boning (ESHB), and steak storage treatments on pH and temperature declines, percentage thaw and cooking losses, Warner-Bratzler shear force, and sensory ratings for samples from longissimus dorsi (LD) and semimembranosus (SM) muscles. Steak storage treatments were fresh (stored until 6 days postmortem at 2C then frozen at -26C) and frozen (frozen 24 or 48 hr postmortem and stored at -26C). In both storage treatments for the LD and SM steaks, ES did not improve taste panel ratings or consistently lower Warner-Bratzler shear force values when compared with control counterparts. When comparing HB with the control for fresh and frozen LD and SM steaks, HB generally decreased tenderness, but no differences ($P > 0.05$) existed between fresh stored SM control and HB steaks. ESHB LD and SM samples were comparable ($P > 0.05$) in tenderness to their controls as evaluated by taste panel and Warner-Bratzler shear force ratings, regardless of the steak storage treatment. Therefore, ES alleviated any toughening effects of HB. When taste panel

and shear force differences ($P < 0.05$) between the fresh and frozen storage treatments existed, the LD steaks responded better to fresh storage. The SM taste panel ratings favored frozen storage, but the SM shear force mean comparisons did not support those observations. When statistical differences existed between fresh and frozen storage for percentage thaw, cooking, and combined loss means, the fresh system was favored. Few differences existed between the control, ES, HB, and ESHB treatments for thaw, cooking, and combined losses.

Introduction

Conventional beef processing techniques involve slaughtering, carcass chilling, then fabrication. Hot boning (HB) refers to the removal of muscles and muscle systems, excess fat, and part or all of the bone from the carcass before conventional chilling. Several researchers (Cuthbertson, 1979; Dvorak, 1979; Kansas State University, 1980) have indicated that labor, energy, materials and supplies, interest on fixed capital, and interest on inventory requirements may be reduced by HB. However, removing beef muscle before the onset of rigor mortis and chilling or freezing the muscle too rapidly may result in a cold induced muscle toughening, "cold shortening" which may be accentuated in prerigor excised muscle (Locker and Hagyard, 1963; Chrystall, 1976). Because of this potential toughening effect, careful processing techniques must be utilized in order to market a high quality hot-boned product to the consumer.

Schmidt and Gilbert (1970) and Schmidt and Keman (1974) noted that the potential detrimental tenderness effects of HB can be overcome by conditioning (15C for 24 to 48 hr) or aging (1C for 8 days) hot-boned beef muscles. Other researchers (Kastner et al., 1973; Falk and Henrickson, 1974; Falk et al., 1975; Kastner and Russell, 1975; Kastner et al., 1976) have avoided tenderness problems due to prerigor excision and/or cold shortening by conditioning beef sides for 3 to 8 hr postmortem at 16C before HB.

To increase processing efficiencies and facilitate continuous product flow, electrical stimulation (ES) can be incorporated into

a HB system. ES speeds the onset of rigor mortis (Will et al., 1979) so carcasses may be hot boned soon postmortem without the need for carcass or muscle conditioning or aging to avoid prerigor excision and cold shortening effects.

Gilbert and Davey (1976) and Gilbert et al. (1977) electrically stimulated beef carcasses at 30 min postmortem with 3600 volts, 2 amps, and 15 hertz of alternating current for 2 min. Gilbert and Davey (1976) rapidly chilled (2C) the sides, hot boned the semimembranosus (SM), longissimus dorsi (LD), biceps femoris, and gluteus medius at 5 hr postmortem and aged the cuts for 72 hr at 10C before freezing, or immediately froze the cuts at -18C; whereas, Gilbert et al. (1977) hot boned the muscles at 1 hr postmortem, aged them for 46 hr at 5C, or froze them immediately at -35C. Both studies concluded that prerigor excision and freezing after ES does not adversely affect meat tenderness and the advantage of ES is particularly evident if aging is part of the processing procedures. Other researchers (Seideman et al., 1979; Corte et al., 1980) have investigated the concept of combining ES and HB and concluded that tenderness was improved in the LD muscle when compared with non-stimulated control counterparts. These authors drew similar conclusions to those of Gilbert and Davey (1976) and Gilbert et al. (1977).

Besides facilitating HB, ES has also been shown to increase tenderness characteristics of LD steaks from conventionally chilled carcasses (Savell et al., 1977, 1978b,c, 1979; Smith et al., 1977).

Our objective was to evaluate the effects of ES, HB, a combination of ES and HB techniques, and steak storage treatments on the

sensory characteristics and thaw and cooking losses of LD and SM steaks.

Materials and Methods

Forty-eight crossbred steers from 7/8 Simmental x 1/8 Hereford or Angus sires and crossbred dams were obtained from the Roman L. Hruska U.S. Meat Animal Research Center at Clay Center, Nebraska. When delivered to the Kansas State University Beef Research Unit, the average age and weight of the steers were 8 mo and 263 kg, respectively. All animals were fed rations containing varying amounts of sorghum silage, corn, soybean meal, and mineral supplement.

The steers were slaughtered in four groups with each group containing 12 animals. Weight endpoints for slaughter groups 1, 2, 3, and 4 were 441, 494, 560, and 596 kg, respectively.

Each group was slaughtered over a 2-day period with six steers being slaughtered each day. Prior to slaughter, the sides were randomly assigned to 1 of 4 carcass treatments.

Hot carcass weights for slaughter groups 1 to 4 were 262, 309, 351, and 358 kg, respectively. The average quality grade was U.S.D.A. Good.

Postmortem Treatments of Sides and Steaks

Cattle were stunned, exsanguinated, skilled, eviscerated, and divided into sides in a normal manner. The sides were randomly assigned to one of four carcass treatments described below:

Control (C)

Sides were chilled at approximately 5C until 48 hr postmortem. Longissimus dorsi (LD) from the anterior tip of the ilium through the 13th rib and semimembranosus (SM) muscles were excised at 48 hr postmortem and cut into steaks.

Electrical Stimulation (ES)

ES was applied to sides at 45 min postmortem. One stainless steel probe was inserted on the inside of the rear leg approximately 8 cm below the attachment of the achilles tendon and another was inserted laterally along the humerus. ES consisted of a pulsed (1.6 sec on, .8 sec off), 400 volt, 60 hertz, approximately 1 amp alternating current for a duration of 2 min. Sides were chilled at approximately 5C until 24 hr postmortem at which time steaks were cut from the LD and SM muscles.

Hot Boning (HB)

HB was performed on the LD and SM muscles at 2 hr postmortem. Hot-boned muscles were loose wrapped in oxygen impermeable bags and chilled in wire racks at approximately 5C until 24 hr postmortem at which time steaks were cut from the muscles.

Electrical Stimulation and Hot Boning (ESHB)

Sides were electrically stimulated like ES sides and the LD and SM muscles were hot boned, chilled, and cut into steaks as previously described for HB.

Four steaks, 2.5 cm in thickness, were excised from each of the LD (anterior end) and SM (proximal end) muscles for taste panel and Warner-Bratzler shear force evaluations, and paired steaks used for taste panel and shear force analyses were assigned to either a fresh or frozen storage treatment. Frozen storage consisted of vacuum packaging and freezing of the steaks at -26C immediately after removal (24 or 48 hr postmortem). Steaks assigned to the fresh storage treatment were vacuum packaged immediately after excision, aged at 2C until 6 days postmortem, and then were frozen and stored at -26C. Thaw and cooking losses were obtained from steaks used for shear force evaluations.

Temperature Declines

Temperature readings were taken at 2, 4, 6, 8, 10, and 24 hr postmortem. Thermistors were inserted approximately 5.0 cm into the center

of the SM muscle and 20.0 cm above the aitch bone and into the center of the LD opposite the fourth lumbar vertebrae.

pH Declines

Core (1.27 cm) samples for pH determinations were excised from the LD (opposite the 5th lumbar vertebrae) and SM (2.5 cm above the aitch bone) muscles at 45 min (before stimulation), 2, 4, 6, 8, and 24 hr postmortem. One to 2 g of muscle were blended with 10 ml of 5mM NaIAc in 150mM KCl (Bendall, 1973). The pH of the meat slurry was read on a Corning digital pH meter equipped with an Orion gel filled combination electrode.

Taste Panel, Warner-Bratzler Shear Force, and Thaw and Cooking Loss Analyses

Maximum frozen storage time for the shear force steaks obtained from sides in the four slaughter groups was 50 days. Steaks used for taste panel evaluation from the four slaughter groups were selected at random, before preparation. Statistically randomizing the steaks was theorized to eliminate any storage period differences between the slaughter groups. The maximum possible storage time was 10 mo.

Steaks for taste panel evaluation were thawed at 2C for 18 hr, removed from the vacuum package, trimmed to a .63 cm subcutaneous fat thickness, and modified oven broiled in a gas rotary oven. Steaks were cooked at 163C until an internal temperature of 70C was reached. Oven and steak temperatures were monitored by a Honeywell Potentiometer according to the recommendations of AMSA (1978). After cooking, taste panel samples were removed by using a drill press unit equipped with a

1.27 cm coring device (Kastner and Henrickson, 1969). Cores were taken perpendicular to the steak surface and kept warm in egg poaching pans filled with warm water.

Taste panel evaluations for flavor, juiciness, myofibrillar tenderness, connective tissue amount, and overall tenderness on the LD and SM muscles were requested from an 8-member trained panel using an 8-point scale (8=extremely intense flavor, juicy, tender, or no connective tissue; 1=extremely bland flavor, dry, tough, or abundant connective tissue) for each response. Panelist selection and training was performed according to procedures outlined in the AMSA Guidelines for Cookery and Sensory Evaluation of Meat (AMSA, 1978).

Panelists were positioned randomly in individual booths equipped with red fluorescent lighting, served a sample, instructed to expectorate each sample, and rinse their mouth with water between samples. Eight samples were presented in a statistically randomized order, and no more than two sessions were held per day.

Steaks for Warner-Bratzler shear force analyses were prepared in a slightly different manner. Before thawing at 2C for 18 hr, steaks were removed from the vacuum package, trimmed to a .63 cm subcutaneous fat thickness, and weighed. After thawing, the steaks were lightly blotted, reweighed, and cooked. Cooking procedures were the same as previously described. Cooked steaks were lightly scraped and blotted before weighing and were allowed to cool at 21C for 2 hr before coring and shearing (AMSA, 1978). These recorded weights were used in calculating the percentages of thaw, cooking, and combined losses.

The steaks were cored as previously described. Six cores were removed from each steak and each was sheared once using the Warner-Bratzler shear apparatus. Shear force readings were recorded as peak shear force values.

Statistical Analysis

The experimental design was a completely randomized block design with respect to assigning sides to carcass treatments. Data were analyzed by analysis of variance and means were compared by using the least significance difference method (Snedecor and Cochran, 1978). The analysis was performed by using the General Linear Model procedures on the Statistical Analysis Systems (Barr et al., 1979).

Results and Discussion

Taste Panel and Warner-Bratzler Shear Force

Taste panel results for longissimus dorsi (LD) steaks (Table 1) from C, HB, and ESHB carcass treatments showed improved myofibrillar tenderness due to the fresh steak storage treatment (2C until 6 days postmortem) when compared with the frozen storage treatment (ES, HB, and ESHB steaks frozen 24 hr and C steaks 48 hr postmortem). Fresh stored HB steaks had less ($P < 0.05$) taste panel detectable connective tissue and significantly higher (more tender) myofibrillar and overall tenderness ratings than their frozen counterparts. Fresh stored ESHB steaks responded similarly with the exception of taste panel ratings for connective tissue amount. Fresh stored steaks from all treatments had significantly smaller (more tender) shear force values than frozen

Table 1 - Taste panel[d] and Warner-Bratzler shear force (kg) means for *longissimus dorsi* muscle by carcass and storage treatments

Storage treatments	Carcass treatments C	ES	HB	ESHB	Std. Dev. of Means
			Flavor intensity		
Fresh	6.3	6.3	6.2	6.2	±.07
Frozen	6.4^{b}	6.2^{ab}	6.0^{a}	6.2^{ab}	±.06
			Juiciness		
Fresh	6.1^{ab}	5.9^{a}	6.3^{b}	6.2^{b}	±.10
Frozen	6.3^{b}	6.1^{ab}	6.1^{ab}	6.0^{a}	±.10
			Myofibrillar tenderness		
Fresh	6.5	6.6	6.2	6.4	±.10
Frozen	6.1^{*bc}	6.5^{c}	4.9^{*a}	5.9^{*b}	±.16
			Connective tissue amount		
Fresh	6.9^{b}	6.9^{b}	6.5^{a}	6.8^{b}	±.08
Frozen	6.8^{b}	6.9^{b}	6.1^{*a}	6.7^{b}	±.09
			Overall tenderness		
Fresh	6.5^{b}	6.7^{b}	6.1^{a}	6.5^{b}	±.09
Frozen	6.3^{bc}	6.6^{c}	5.0^{*a}	6.0^{*b}	±.14
			Warner-Bratzler shear force (kg)		
Fresh	3.3^{ab}	3.0^{a}	3.8^{b}	3.0^{a}	±.09
Frozen	4.0^{*b}	3.3^{*a}	4.6^{*c}	3.5^{*ab}	±.15

* Means within same column differ significantly ($P < 0.05$).

abc Means within same row with same or no superscript do not differ significantly ($P > 0.05$).

[d] Flavor intensity, juiciness, myofibrillar tenderness, connective tissue amount, and overall tenderness evaluated on 8-point scale (8=extremely intense, juicy, tender, or none; 1=extremely bland, dry, tough, or abundant).

steaks. When significant differences were observed between the fresh and frozen storage treatments, the fresh treatment was favored. This was particularly true for the HB and ESHB carcass treatments. These various improvements may be explained by the increased aging period for the fresh steaks. It appears that the tenderizing effects of the aging processes were reduced when the steaks were frozen at -26C at either 24 or 48 hr postmortem.

For both the fresh and frozen systems, steaks from the ES carcass treatment were generally comparable to those in the C treatment for all traits listed in Table 1. Westervelt and Stouffer (1978) found that ES did not improve tenderness of the porcine LD; however, Smith et al. (1977) found ES increased beef muscle tenderness by 12 to 55 percent. Savell et al. (1977, 1978b,c, 1979) and McKeith et al. (1981) reported that ES of beef carcasses produced less panel detectable connective tissue, improved tenderness, flavor, overall palatability, and lower shear force values (Grusby et al., 1976; Riley et al., 1980) when compared with unstimulated counterparts.

With exception of taste panel detectable connective tissue amount and overall tenderness, no differences ($P > 0.05$) were observed when the fresh stored steaks from the HB carcass treatment were compared with C counterparts. Within the frozen storage treatment, HB exhibited less desirable ($P < 0.05$) taste panel mean ratings for flavor intensity, myofibrillar tenderness, connective tissue amount, overall tenderness, and larger ($P < 0.05$) shear force values than C counterparts. These results are consistent with previous research. Kastner et al. (1973) also found LD muscles that were hot boned at 2 hr and frozen at 48 hr

postmortem to be less tender than C counterparts. This indicates that the fresh storage treatment alleviated some of the detrimental effects of HB at 2 hr postmortem.

Considering the tenderness indicating attributes in Table 1, ESHB was equal to C within both the fresh and frozen storage treatments. ES alleviated any tenderness differences that existed between C and HB. This was particularly true for the frozen storage treatment. In addition to facilitating the hot-boning technique, ES exerted no consistent detrimental effects on LD flavor and juiciness. These results agree with those of Gilbert and Davey (1976), Gilbert et al. (1977), Taylor (1979), Corte et al. (1980), and Kastner et al. (1980).

Comparisons between HB and ESHB in the fresh and frozen storage treatments generally support the C versus HB and ESHB comparisons (Table 1). Regardless of the steak storage treatment, ESHB gave equal or superior results when compared with HB for all the traits in Table 1.

Taste panel results for the semimembranosus (SM) steaks (Table 2) indicate no differences ($P > 0.05$) between the fresh and frozen storage treatments for all carcass treatments for flavor intensity and juiciness. When considering taste panel myofibrillar tenderness, detectable connective tissue amount, and overall tenderness, differences ($P < 0.05$) were generally found in favor of the frozen storage treatment. However, these differences were not supported by Warner-Bratzler shear force comparisons as no statistical differences were observed for shear force means between the fresh and frozen storage treatments for each carcass treatment.

Table 2 - Taste panel[c] and Warner-Bratzler shear force (kg) means for *semimembranosus* muscle by carcass and storage treatments

Storage treatments	Carcass treatments C	ES	HB	ESHB	Std. Dev. of Means
			Flavor intensity		
Fresh	6.1	6.0	6.0	6.1	±.05
Frozen	6.1	6.1	6.0	6.1	±.05
			Juiciness		
Fresh	5.9	5.8	5.9	5.9	±.07
Frozen	6.0	5.9	5.9	5.9	±.09
			Myofibrillar tenderness		
Fresh	5.8	5.8	5.6	5.8	±.07
Frozen	6.3^{*b}	6.2^{*b}	5.6^{a}	6.1^{*b}	±.08
			Connective tissue amount		
Fresh	5.4	5.5	5.4	5.5	±.07
Frozen	5.9^{*ab}	6.1^{*b}	5.8^{*a}	5.9^{*ab}	±.05
			Overall tenderness		
Fresh	5.5^{ab}	5.6^{b}	5.3^{a}	5.6^{b}	±.07
Frozen	6.0^{*b}	6.1^{*b}	5.6^{*a}	6.0^{*b}	±.07
			Warner-Bratzler shear force (kg)		
Fresh	4.7^{ab}	4.6^{ab}	5.1^{b}	4.5^{a}	±.12
Frozen	4.6^{a}	4.9^{a}	5.4^{b}	4.5^{a}	±.17

* Means within same column differ significantly ($P < 0.05$).

ab Means within same row with same or no superscript do not differ significantly ($P > 0.05$).

c Flavor intensity, juiciness, myofibrillar tenderness, connective tissue amount, and overall tenderness evaluated on 8-point scale (8=extremely intense, juicy, tender, or none; 1=extremely bland, dry, tough, or abundant).

When comparing C to ES within the fresh and frozen storage treatments, no differences ($P > 0.05$) were found for any of the traits listed in Table 2. This was the same trend observed for LD steaks (Table 1).

HB was equal ($P > 0.05$) to C for all traits when the fresh storage treatment was considered. These results agree with Schmidt and Keman (1974) who observed SM muscles hot boned as soon as 1 hr postmortem to be as tender as control counterparts if aged until 8 days postmortem. However, for the same comparison within the frozen storage treatment, HB was scored significantly lower (less tender) for myofibrillar and overall tenderness than C. These results were supported by shear force mean comparisons between C and HB which agree with those of Kastner et al. (1973). As with the LD (Table 1), aging steaks at 2C until 6 days postmortem alleviated the detrimental effects of HB. These observations along with shear force results make it difficult to rationalize why taste panel connective tissue amount, myofibrillar tenderness, and overall tenderness ratings generally favored the frozen storage treatment. However, Wu et al. (1981) observed SM connective tissue solubility decreased with increased aging at 2C.

Regardless of the SM steak storage treatment, ESHB was equal ($P > 0.05$) to C. These results agree with Gilbert and Davey (1976), Gilbert et al. (1977), Taylor (1979), and Corte et al. (1980). In addition, our ESHB treatment within the fresh storage treatment improved upon the method of Kastner et al. (1980) who indicated that SM muscles from carcasses electrically stimulated at 1 hr postmortem, hot boned at 2 hr postmortem, and aged until 6 days postmortem

were less tender than control counterparts. This could have been due to our use of pulsed versus continuous stimulation and stimulating at 45 min rather than 1 hr postmortem. The differences between C and HB within the frozen storage treatment were negated by ES.

Comparisons between HB and ESHB in the fresh and frozen SM steak storage treatments generally support the C versus HB and ESHB comparisons. Regardless of the steak storage treatment, ESHB gave equal or superior results when compared to HB for all traits in Table 2.

pH and Temperature Declines

Figures 1, 2, 3, and 4 illustrate pH and temperature declines for the LD and SM muscles by carcass treatments. It is generally accepted that cold shortening can take place if muscles reach 10C in less than 10 hr postmortem (Locker and Hagyard, 1963) or before pH 6.0 has been reached (Chrystall, 1976).

ES was effective in speeding the rate of pH decline of ES and ESHB LD muscles versus non-stimulated C and HB counterparts (Fig. 1). Postmortem pH decline rates were comparable for ES and ESHB. C and HB muscle pH decline rates were similar.

C and ES muscles chilled at comparable rates while HB and ESHB muscle temperature decline rates were virtually the same, but somewhat faster than C and ES counterparts (Fig. 2).

Warner-Bratzler shear force and taste panel means (Table 1) generally indicated that the hot-boned LD muscles were significantly less tender than C and ESHB samples. C and ESHB were equal ($P > 0.05$) in tenderness as generally were C and ES. Hot-boned LD muscles chilled

Figure 1 - Postmortem pH declines for the longissimus dorsi muscle by carcass treatment

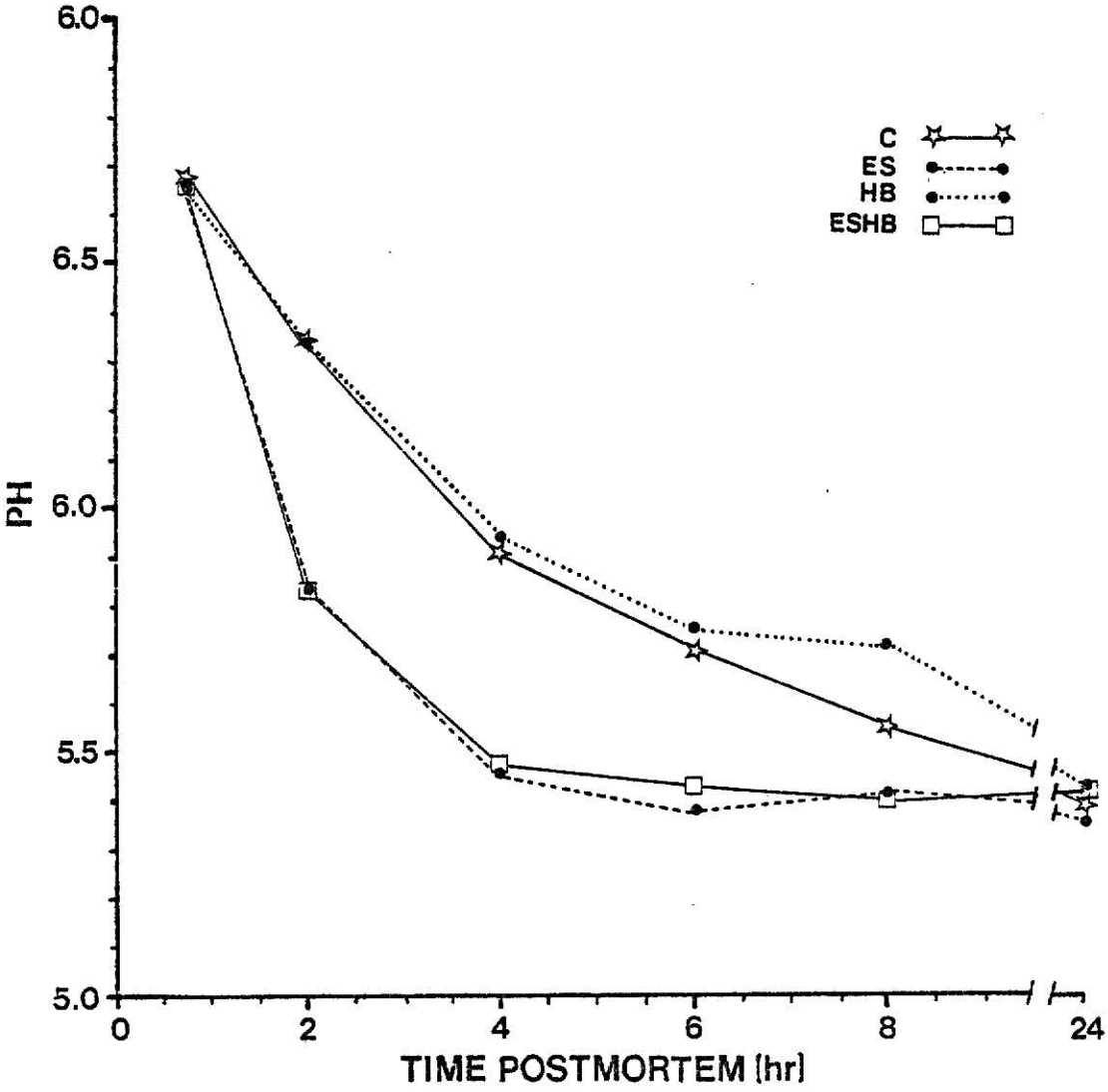

6.0
6.5
6.0
5.5
5.0
pH
0
2
4
6
8
24
TIME POSTMORTEM [hr]
C
ES
HB
ESHB

Figure 2 - Postmortem temperature declines for the longissimus dorsi by carcass treatment

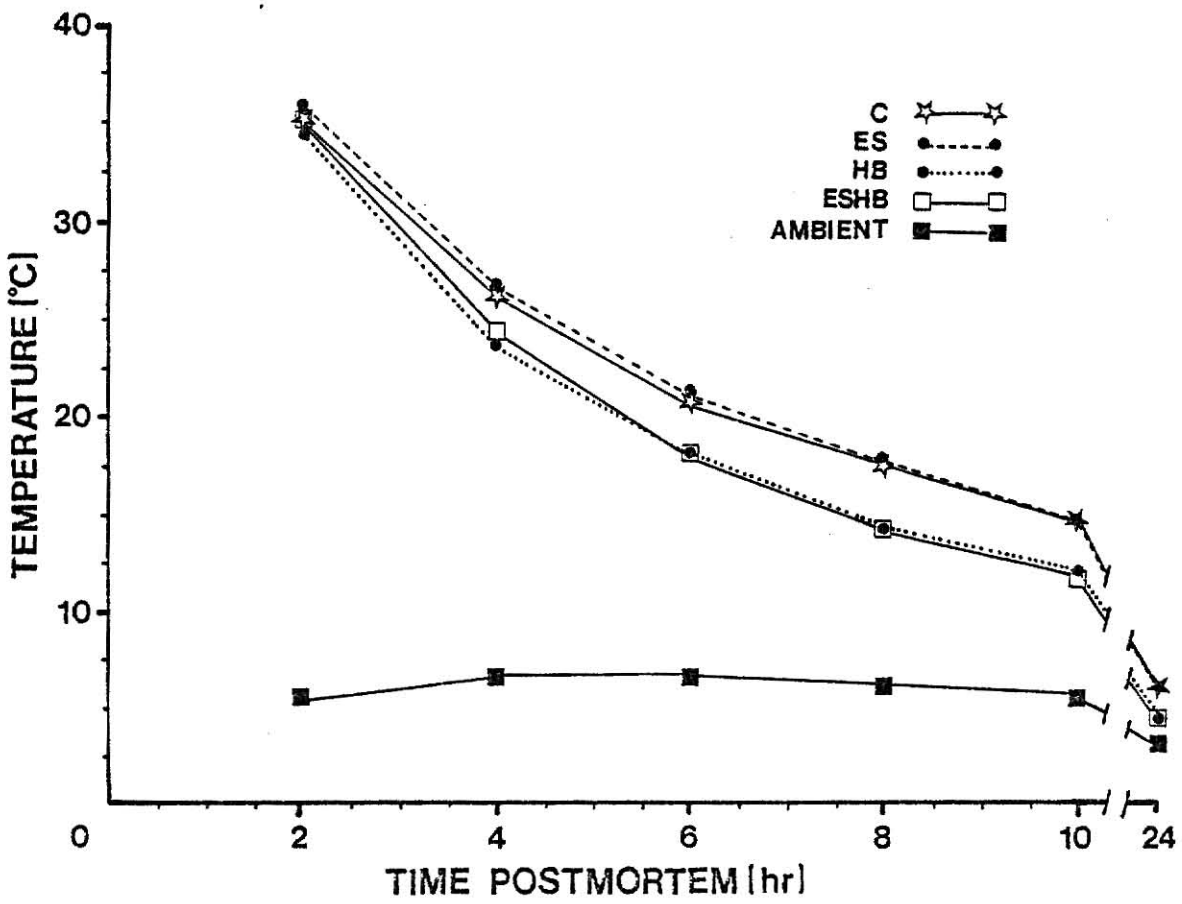

40
30
20
10
0
TEMPERATURE [°C]
C
ES
HB
ESHB
AMBIENT
2
4
6
8
10
24
TIME POSTMORTEM [hr]

Figure 3 - Postmortem pH declines for the semimembranosus muscle by carcass treatment

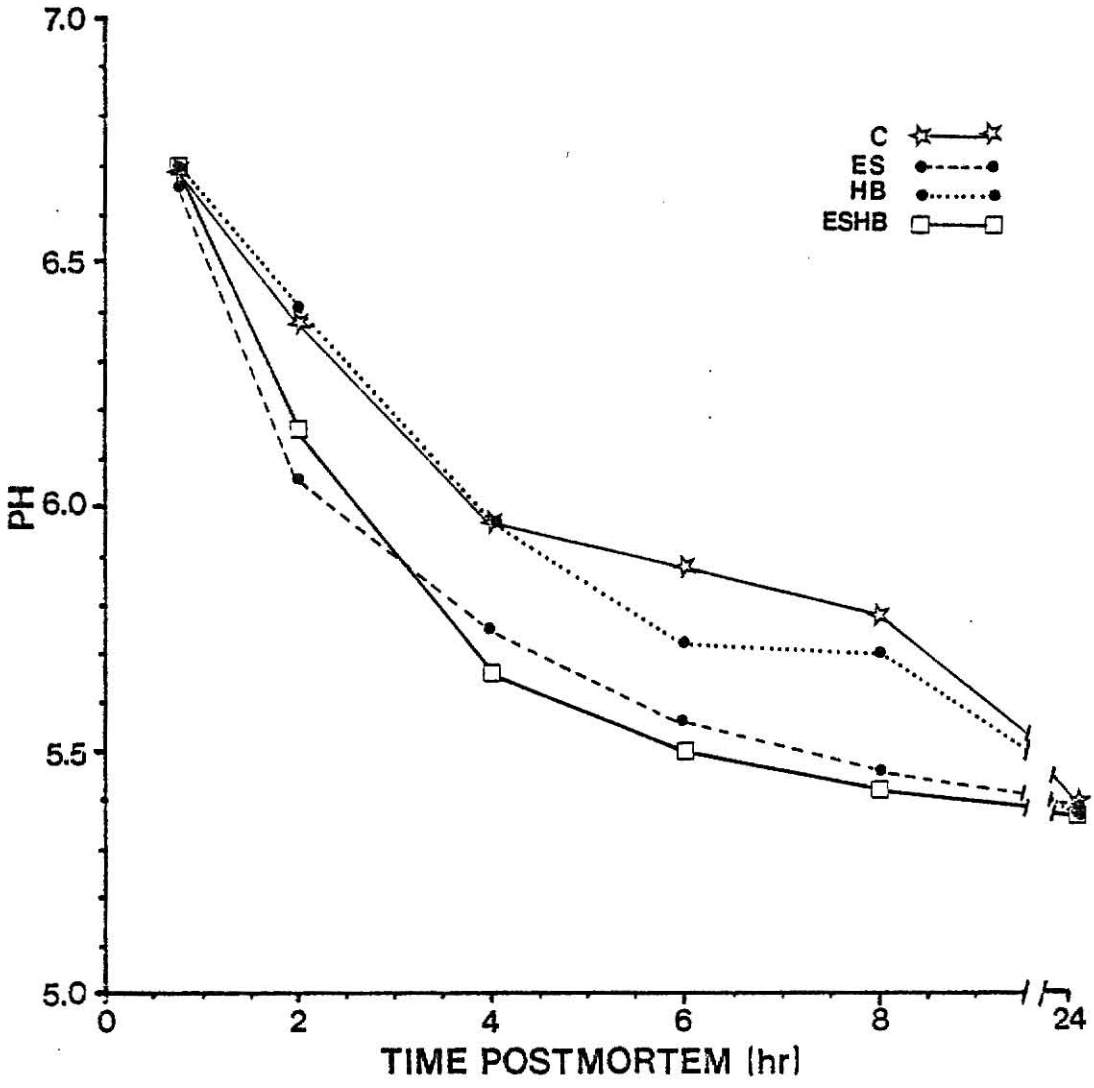
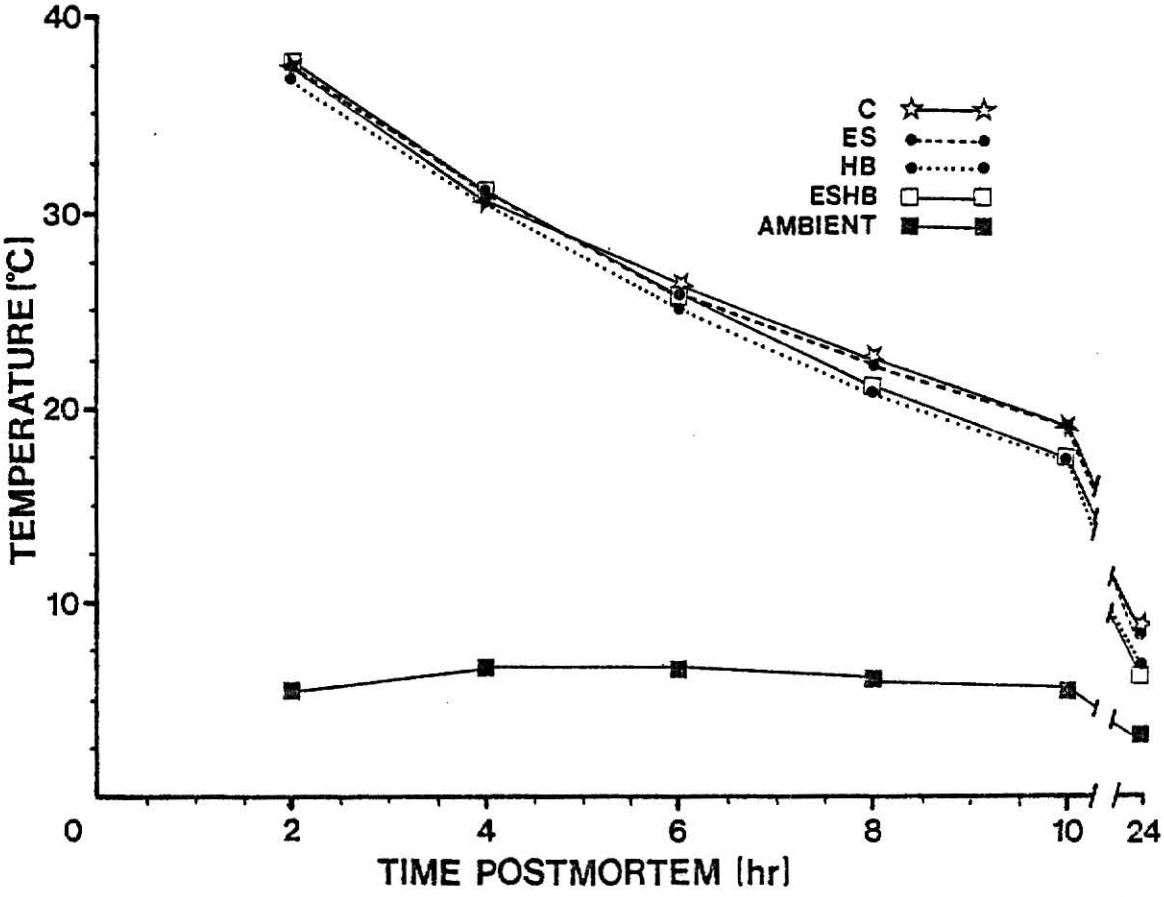

7.0
6.5
6.0
5.5
5.0
PH
C
ES
HB
ESHB
0
2
4
6
8
24
TIME POSTMORTEM (hr)

Figure 4 - Postmortem temperature declines for the semimembranosus muscle by carcass treatment


40
30
20
10
0
2
4
6
8
10
24
TEMPERATURE [°C]
TIME POSTMORTEM [hr]
C
ES
HB
ESHB
AMBIENT

at a somewhat faster rate than C counterparts and when excised at 2 hr postmortem the HB and pH was 6.34 (Fig. 1). Even though the hot-boned muscles did not meet the temperature conditions for cold shortening outlined previously, they were at 12C within 10 hr postmortem. The prerigor excision of the hot-boned LD muscles may have made them more responsive to shortening stimuli causing the hot-boned samples to be less tender than C counterparts. The mean pH value for ESHB LD muscles was 5.84 when excised (Fig. 1). Therefore, they were apparently not as responsive to shortening stimuli as were the less tender HB counterparts excised at pH 6.34 and chilled at the same rate (Fig. 2). Even though the ESHB muscles reached 12C in 10 hr postmortem, the pH (5.84) upon excision was apparently low enough to avoid any adverse shortening effects. Consequently, C and ESHB LD muscles were equal ($P > 0.05$) in tenderness. ES had a lower pH than C until approximately 24 hr postmortem, but both chilled at the same rate which was not sufficiently rapid (Fig. 2) to cause cold induced toughening in C relative to ES (Locker and Hagyard, 1963; Chrystall, 1976) regardless of the pH. In addition, the C treatment pH was 6.0 before the muscle temperature reached 10C (Figs. 1 and 2). If our assumption that cold shortening did not occur in the LD muscles from the C treatment, then our ES conditions did not consistently induce alternative modes of tenderization proposed by other researchers (Locker and Daines, 1976; Dutson et al., 1977, 1980a,b; Savell et al., 1978a). This was concluded since C was generally equal to ES ($P > 0.05$) for all traits in Table 1. The only exception was shear force for the frozen storage treatment.

As for the LD muscle, ES was effective in speeding the rate of pH decline of ES and ESHB SM muscles versus C and HB muscles. Postmortem pH decline rates were comparable for ES and ESHB. C and HB muscles were also similar (Fig. 3). This was particularly true the first 4 to 5 hr postmortem.

SM muscles from all carcass treatments chilled at comparable rates within the first 6 hr postmortem, but HB and ESHB chilling rates were slightly faster from 6 to 10 hr postmortem than C and ES (Fig. 4).

All carcass treatments were above 10C at 10 hr postmortem and pH 6.0 was attained before 10C was reached (Figs. 3 and 4); therefore, cold shortening conditions established by Locker and Hagyard (1963) and Chrystall (1976) were not attained.

However, for the frozen storage treatment, the SM muscles from the hot-boned treatment were generally less tender than C counterparts. Frequently HB samples were less tender than ESHB samples. C and ESHB were consistently equal ($P > 0.05$) as were C and ES (Table 2). These same trends were also observed for the LD muscle (Table 1).

SM muscles from the hot-boned treatment had a pH of 6.41 when excised at 2 hr postmortem. Therefore, prerigor excision may have allowed these muscles (frozen storage treatment) to freely contract and become less tender than C muscles restrained in the carcass until excised at 48 hr postmortem. SM muscles from the ESHB treatment had a lower (6.16) mean pH than HB counterparts (6.41) when excised at 2 hr postmortem and obviously did not toughen as much due to prerigor excision as HB (Table 2). Even though ESHB SM muscles were excised at 2 hr postmortem, the pH was apparently sufficiently low to avoid

muscle toughening relative to C (Table 2). ES had a lower pH than C until 24 hr postmortem, but both chilled at the same rate which was not sufficiently rapid to cause cold induced toughening in either muscle (Locker and Hagyard, 1963; Chrystall, 1976). Also, the C SM pH was 6.0 before the muscle temperature reached 10C (Figs. 3 and 4). As with the LD, if our assumption that cold shortening did not occur in the C SM, then ES did not induce alternative modes of tenderization proposed by other researchers (Locker and Daines, 1976; Dutson et al., 1977, 1980a,b; Savell et al., 1978a) because C was equal to ES ($P > 0.05$) for all traits in Table 2.

In all cases it is possible that ES exerted an additional tenderizing effect on hot-boned muscles from stimulated carcasses. However, this is not supported by C versus ES comparisons which were almost always equal for both the LD and SM muscles (Tables 1 and 2).

Thaw and Cooking Losses

Data from Table 3 involving percentage thaw, cooking, and combined losses show few differences ($P < 0.05$). However, when statistical differences for percentage thaw, cooking, and combined loss means between LD and SM steaks stored fresh and frozen were observed, the fresh system was favored. This was particularly true for the ESHB carcass treatment for both muscles.

Although generally no differences ($P > 0.05$) were observed between carcass treatments within the fresh and frozen storage systems for the LD muscle, a trend of greater cooking and combined losses was noted for ES steaks within the fresh storage treatment. These results for C

Table 3 - Percentage thaw, cooking, and combined loss means for longissimus dorsi and semimembranosus muscles by carcass and storage treatments

Storage treatments	Carcass treatments C	ES	HB	ESHB	Std. Dev. of Means
			Thaw loss (%)		
			Longissimus dorsi		
Fresh	2.4	2.4	2.7	2.8	±.25
Frozen	4.3^{b}*	3.4^{ab}*	3.1^{a}	4.1^{b}*	±.27
			Semimembranosus		
Fresh	2.6	2.7	3.1	2.6	±.22
Frozen	2.9^{ab}	2.5^{ab}	3.3^{b}	2.4^{a}	±.27
			Cooking loss (%)		
			Longissimus dorsi		
Fresh	27.9	28.6	27.4	25.8	±.97
Frozen	30.4*	28.3	28.7	29.6*	±.87
			Semimembranosus		
Fresh	34.6^{b}	33.9^{ab}	35.6^{b}	31.1^{a}	±.92
Frozen	33.4	35.2	34.3	34.7*	±.81
			Combined loss (%)		
			Longissimus dorsi		
Fresh	29.7	30.3	29.4	27.9	±.88
Frozen	33.4*	30.7	30.9	32.5*	±.83
			Semimembranosus		
Fresh	36.2^{ab}	35.6^{ab}	37.6^{b}	34.1^{a}	±.82
Frozen	35.3	36.8	36.4	36.2*	±.80

* Means within same column differ significantly ($P < 0.05$).

ab Means within same row with same or no superscript do not differ significantly ($P > 0.05$).

versus ES are in agreement with Savell et al. (1978b) and Cross et al. (1979). Cooking and combined loss comparisons between carcass treatments for the LD and SM samples were smallest for ESHB within the fresh storage treatment. These results disagree with Cross and Tennent (1980) who found increased cooking losses for ESHB as compared with C samples.

Summary

Taste panel and shear force results (Table 1) favored the fresh storage treatment for the LD muscle; whereas, taste panel results (Table 2) favored the frozen storage treatment for the SM muscle. SM shear force results did not support the taste panel observations. In addition, when statistical differences for percentage thaw, cooking, and combined losses between LD and SM steaks stored fresh and frozen were observed, the fresh system was favored (Table 3). However, these differences (Table 3) were primarily applicable for the ESHB carcass treatment. Therefore, from an overall standpoint neither storage treatment had a distinct advantage over the other, but the fresh storage treatment may be somewhat superior, particularly when ES and HB are combined (ESHB).

Contrary to observations of other researchers (Savell et al., 1977, 1978b,c, 1979; Smith et al., 1977), ES did not improve taste panel tenderness ratings or consistently lower shear force values relative to C for either the LD or SM (Tables 1 and 2). However, had C been chilled at faster rates than those shown in Figures 2 and 4, ES may have been more beneficial. Our chilling rates were not rapid enough nor our pH high enough when the muscles reached 10C to cause

cold shortening (Locker and Hagyard, 1963; Chrystall, 1976). This appears to be particularly true for C muscles restrained and chilled in the carcass. Therefore, ES did not appear to induce alternative modes of tenderization suggested by other researchers (Locker and Daines, 1976; Dutson et al., 1977, 1980a,b; Savell et al., 1978a) as the ES SM and LD samples were almost always equal to their controls. The only exception was LD shear force for the frozen storage treatment.

Within the fresh storage treatment for the LD muscle, HB caused some reduction in tenderness relative to C (Table 1); whereas, for the SM muscle HB was equal to C (Table 2). Within the frozen storage treatment for both muscles, C was consistently superior in tenderness to HB. However, when ES was combined with HB, ESHB was equal in tenderness to C regardless of the muscle (LD or SM) or storage treatment (fresh or frozen). ES alleviated any tenderness differences that existed between C and HB, particularly for the frozen storage treatment.

REFERENCES

A.M.S.A. 1978. "Guidelines for Cookery and Sensory Evaluation of Meat." Published by the American Meat Science Association in cooperation with the National Livestock and Meat Board.

Barr, A.J., Goodnight, J.H., Sall, J.P., Blair, W.H., and Chilko, D.M. 1979. "SAS User's Guide," p. 237, 245, SAS Institute, Inc., Raleigh, North Carolina.

Bendall, J.R. 1973. In "Structure and Function of Muscle." Vol. 2. p. 243. G.H. Bourne, Ed. Academic Press, New York.

Chrystall, B.B. 1976. Accelerated conditioning of meat. Proceedings of 18th Meat Ind. Res. Conf. MIRINZ. Hamilton, New Zealand. 5.

Corte, O.O., Cia, G., Picche, V., Procknor, M.L.S.C., and Delazari, I. 1980. Electrical stimulation and hot boning of beef carcasses associated with chilling or freezing. Proceedings of 26th European Meeting of Meat Research Workers. Colorado Springs, Colorado. 2:53.

Cross, H.R., Smith, G.C., Kotula, A.W., and Muse, D.A. 1979. Effects of electrical stimulation and shrouding method on quality and palatability of beef carcasses. J. Food Sci. 44:1560.

Cross, H.R. and Tennent, I. 1980. Accelerated processing systems for USDA Choice and Good beef carcasses. J. Food Sci. 45:765.

Cuthbertson, A. 1979. Hot processing of meat: a review of the rationale and economic implications. Meat and Livestock Commission, Bletchley, Milton Keynes, United Kingdom.

Dutson, T.R., Yates, L.D., Smith, G.C., Carpenter, Z.L., and Hostetler, R.L. 1977. Rigor onset before chilling. Proc. Recip. Meat Conf. 30:79.

Dutson, T.R., Smith, G.C., and Carpenter, Z.L. 1980a. Lysosomal enzyme distribution in electrically stimulated ovine muscle. J. Food Sci. 45:1097.

Dutson, T.R., Smith, G.C., Savell, J.W., and Carpenter, Z.L. 1980b. Possible mechanisms by which electrical stimulation improves meat tenderness. Proceedings of 26th European Meeting of Meat Research Workers. Colorado Springs, Colorado. 2:84.

Dvorak, N. 1979. On-rail hot beef boning: an idea whose time has come. Proceedings of 21st Annual Meat Science Institute. Athens, Georgia. 45.

Falk, S.N. and Henrickson, R.L. 1974. Feasibility of hot boning the bovine carcass. Animal Science Research. Oklahoma Agric. Exp. Station. 145.

Falk, S.N., Henrickson, R.L., and Morrison, R.D. 1975. Effect of boning beef carcasses prior to chilling on meat tenderness. J. Food Sci. 40:1075.

Gilbert, K.V. and Davey, C.L. 1976. Carcass electrical stimulation and early boning of beef. N.Z. J. Agric. Res. 19:429.

Gilbert, K.V., Davey, C.L., and Newton, K.G. 1977. Electrical stimulation and the hot boning of beef. N.Z. J. Agric. Res. 20:139.

Grusby, A.H., West, R.L., Carpenter, J.W., and Palmer, A.Z. 1976. Effects of electrical stimulation on tenderness. J. Anim. Sci. 42:253.

Kansas State University. 1980. Economic feasibility of hot processing beef carcasses. Kansas Agric. Exp. Station Bulletin. Bulletin 639.

Kastner, C.L. and Henrickson, R.L. 1969. Providing uniform meat cores for mechanical shear force measurement. J. Food Sci. 34:603.

Kastner, C.L., Henrickson, R.L., and Morrison, R.D. 1973. Characteristics of hot-boned bovine muscle. J. Anim. Sci. 36:484.

Kastner, C.L. and Russell, T.S. 1975. Characteristics of conventionally and hot-boned bovine muscle excised at various conditioning periods. J. Food Sci. 40:747.

Kastner, C.L., Sullivan, D.P., Ayaz, M., and Russell, T.S. 1976. Further evaluation of conventional and hot-boned bovine longissimus dorsi muscle excised at various conditioning periods. J. Food Sci. 41:97.

Kastner, C.L., Dikeman, M.E., Nagele, K.N., Lyon, M., Hunt, M.C., and Kropf, D.H. 1980. Effects of carcass electrical stimulation and hot boning on selected beef muscles. Proceedings of 26th European Meeting of Meat Research Workers. Colorado Springs, Colorado. 2:40.

Locker, R.H. and Hagyard, C.J. 1963. A cold shortening effect in beef muscles. J. Sci. Fd. Agric. 14:787.

Locker, R.H. and Daines, G.J. 1976. Tenderness in relation to the temperature of rigor onset in cold shortened beef. J. Sci. Fd. Agric. 27:193.

McKeith, F.K., Smith, G.C., Savell, J.W., Dutson, T.R., Carpenter, Z.L., and Hammons, D.R. 1981. Effects of certain electrical stimulation parameters on quality and palatability of beef. J. Food Sci. 46:13.

Riley, R.R., Savell, J.W., Smith, G.C., and Shelton, M. 1980. Quality, appearance, and tenderness of electrically stimulated lamb. J. Food Sci. 45:119.

Savell, J.W., Smith, G.C., Dutson, T.R., Carpenter, Z.L., and Suter, D.A. 1977. Effect of electrical stimulation on palatability of beef, lamb and goat meat. J. Food Sci. 42:702.

Savell, J.W., Dutson, T.R., Smith, G.C., and Carpenter, Z.L. 1978a. Structural changes in electrically stimulated beef muscle. J. Food Sci. 43:1606.

Savell, J.W., Smith, G.C., and Carpenter, Z.L. 1978b. Beef quality and palatability as affected by electrical stimulation and cooler aging. J. Food Sci. 43:1666.

Savell, J.W., Smith, G.C., and Carpenter, Z.L. 1978c. Effect of electrical stimulation on quality and palatability of light-weight beef carcasses. J. Anim. Sci. 46:1221.

Savell, J.W., Smith, G.C., Carpenter, Z.L., and Parrish, F.C., Jr. 1979. Influence of electrical stimulation on certain characteristics of heavy-weight beef carcasses. J. Food Sci. 44:911.

Schmidt, G.R. and Gilbert, K.V. 1970. The effect of muscle excision before the onset of rigor mortis on the palatability of beef. J. Food Technol. 5:331.

Schmidt, G.R. and Keman, S. 1974. Hot boning and vacuum packaging of eight major bovine muscles. J. Food Sci. 39:140.

Seideman, S.G., Smith, G.C., Dutson, T.R., and Carpenter, Z.L. 1979. Physical, chemical and palatability traits of electrically stimulated, hot-boned, vacuum-packaged beef. J. Food Prot. 42:651.

Smith, G.C., Dutson, T.R., Carpenter, Z.L., and Hostetler, R.L. 1977. Using electrical stimulation to tenderize meat. Proceedings of 19th Meat Ind. Res. Conf. American Meat Institute Foundation. Arlington, Virginia. 147.

Snedecor, G.W. and Cochran, W.G. 1978. Statistical Methods. (6th Ed.). The Iowa State University Press, Ames, Iowa.

Taylor, A.A. 1979. Hot boning and electrical stimulation of beef carcasses. J. Sci. Fd. Agric. 30:1104.

Westervelt, R.G. and Stouffer, J.R. 1978. Relationships among spinal cord severing, electrical stimulation and postmortem quality characteristics of the porcine carcass. J. Anim. Sci. 46:1206.

Will, P.A., Henrickson, R.L., Morrison, R.D., and Odell, G.V. 1979. Effect of electrical stimulation on ATP depletion and sarcomere length in delay-chilled bovine muscle. J. Food Sci. 44:1646.

Wu, J.J., Dutson, T.R., and Carpenter, Z.L. 1981. Effect of post-mortem time and temperature on the release of lysosomal enzymes and their possible effect on bovine connective tissue components of muscle. J. Food Sci. (accepted).

Chapter IV

CONTINUOUS VERSUS INTERMITTENT ELECTRICAL STIMULATION OF BEEF CARCASSES AND THEIR EFFECT ON HOT-BONED *LONGISSIMUS DORSI* MUSCLE pH DECLINE

ABSTRACT

Two groups of crossbred steers of known backgrounds were slaughtered and sides were electrically stimulated and hot boned. Group I consisted of 46 sides that were electrically stimulated at 1 hr postmortem with 400 volts of continuous, 60 hertz, alternating current. Approximately 1.0 amp was delivered through the carcass for 2 min. At 2 hr postmortem the *longissimus dorsi* (LD) muscle was hot boned. Group II contained 24 sides that were electrically stimulated and hot boned similarly to those sides in Group I, except electrical stimulation was administered at 45 min postmortem and the stimulation parameters were altered to incorporate an intermittent stimulation. The intermittent stimulation lasted 2 min and consisted of a series of 1.6 sec "on" pulses with 0.8 sec between pulses.

The pH readings were recorded at 1, 2, 4, 6, 8, and 24 hr postmortem for Group I and 45 min, 2, 4, 6, 8, and 24 hr postmortem for Group II.

Continuous and intermittent electrical stimulation accelerated postmortem pH decline in the LD muscle; however, intermittent stimulation gave the lowest muscle pH values at all postmortem times.

Introduction

Several researchers have studied the effects of hot boning (HB) on the tenderness of beef muscle (Schmidt and Gilbert, 1970; Kastner et al., 1973; Falk and Henrickson, 1974; Schmidt and Keman, 1974; Falk et al., 1975; Kastner and Russell, 1975; Kastner et al., 1976). Schmidt and Gilbert (1970) found that conditioning beef muscle at 15C and HB muscles at 2 hr postmortem resulted in tender meat. Kastner et al. (1973) hot boned muscle at 2, 5, and 8 hr postmortem. Significantly higher Warner-Bratzler shear force values were found in the 2 and 5 hr hot-boned cuts when compared with counterparts from sides chilled at 2C for 48 hr before boning. Kastner et al. (1973) concluded that to insure tender cuts, muscles should not be excised before 8 hr postmortem. Although research indicates that HB can be accomplished without the detrimental effects of muscle toughening (Schmidt and Gilbert, 1970; Kastner et al., 1973; Falk and Henrickson, 1974; Schmidt and Keman, 1974; Falk et al., 1975; Kastner and Russell, 1975; Kastner et al., 1976), meat palatability may be altered by the HB technique used. Muscles may shorten under normal carcass chilling conditions; however, removing prerigor muscle from its skeletal restraints could lead to somewhat more shortening and toughening. When prerigor muscle is exposed to rapid chilling conditions, muscle shortening and toughening are enhanced by "cold shortening" (Locker and Hagyard, 1963).

Bendall and Rhodes (1976) stated that "cold shortening" does not occur at pH 6.0 or below. Therefore, combining electrical stimulation (ES) and hot boning (HB) (ESHB) seems beneficial since ES has been shown

to accelerate postmortem pH decline and the onset of rigor mortis (de Fremery and Pool, 1959; Davey et al., 1976; McCollum and Henrickson, 1977; Will et al., 1979). However, the optimal combination of ES parameters (continuous or intermittent stimulation, voltage (V), alternating current (AC) or direct current (DC), postmortem stimulation time, duration of stimulation, amperage (A), and frequencies or hertz (Hz)) required to give the fastest rate of rigor onset has not been determined. Carse (1973) proposed that increasing pulse voltage instead of frequency would accelerate postmortem glycolysis as measured by pH decline. Lamb carcasses were electrically stimulated at 30 min postmortem with 0 to 250 V DC wave pulses (2 to 13.5 msec duration) delivered at rates from 3 to 17.5 per sec. Using 250 V the pH of 6.0 was reached in the electrically stimulated sides in 3 hr compared to 15.4 hr postmortem for the non-stimulated controls. Lower voltages were less effective. Chrystall and Hagyard (1975) concluded low pH levels (5.7 to 6.0) were achieved and lamb muscle toughening was minimized upon rapid chilling when ES was delivered for 1 min within 5 min after exsanguination with 5 msec pulses of 15 Hz and 0.8 to 1.0 A peak AC. Chrystall and Hagyard (1975) found that pH 6.0 was reached in 1.5 to 2 hr postmortem when these ES parameters were used. Bendall et al. (1976) and Bendall and Rhodes (1976) found that electrically stimulating beef sides at 50 min postmortem with 700 V, 25 Hz, applied for 2 min resulted in muscles reaching pH 6.0 in 1 to 3.5 hr and pH 5.7 in 2.5 to 4.9 hr.

Nichols and Cross (1980) studied the combined effects of ES and HB on pH decline of the longissimus dorsi (LD) and semimembranosus (SM)

muscles. Beef sides were stimulated 1 hr postmortem with approximately 200 V of continuous, 60 Hz AC for 2 min and hot boned at 1, 2, or 4 hr postmortem. They concluded that their methodology of ES and HB had a significant effect on the rate of pH decline compared with non-stimulated controls. Hot-boned LD muscle reached pH 6.0 at the time of excision (2 hr postmortem). Other researchers (Gilbert and Davey, 1976; Gilbert et al., 1977; Seideman et al., 1979; Corte et al., 1980) have also evaluated the use of ES in facilitating HB. Corte et al. (1980) electrically stimulated beef sides 30 min after bleeding with intermittent, 700 V, 60 Hz AC for 2 min and hot boned the muscles at 45 min postmortem. The initial pH values for the LD and SM were between 6.75 and 6.85. In the stimulated and hot-boned cuts, the muscle pH reached 6.1 to 6.2 at 1.0 to 1.5 hr after bleeding. In control sides, the same pH range was not reached until 8 hr postmortem.

Our experiment was designed to determine which method of ES (continuous or intermittent) combined with HB induced the most rapid postmortem pH decline.

Materials and Methods

Two groups of crossbred steers were obtained from the R. L. Hruska U.S. Meat Animal Research Center at Clay Center, Nebraska. All steers were slaughtered at the Kansas State University Meats Laboratory. U.S.D.A. quality grades ranged from Good to low Choice.

Cattle in both groups were slaughtered and divided into sides, electrically stimulated and hot boned (ESHB). Group I consisted of 46 sides that were stimulated at 1 hr postmortem with 400 V of continuous, 60 Hz AC for 2 min. Approximately 1.0 A was delivered through the carcass. Two hr after slaughter the LD muscles (anterior tip of ilium through the thirteenth rib) were hot boned, stored in oxygen impermeable bags, and chilled at 5C. The electrical current was applied by inserting a stainless steel probe on the inside of the rear leg approximately 8 cm below the attachment of the achilles tendon and another probe inserted laterally along the humerus.

Group II consisted of 24 sides that were electrically stimulated and hot boned (ESHB) similarly to those sides in Group I, except electrical stimulation was administered at 45 min postmortem for 2 min and the stimulation parameters were altered to incorporate an intermittent stimulation (a series of 1.6 sec "on" pulses with 0.8 sec between pulses).

pH Decline

Beginning at 1 hr postmortem, pH readings were recorded for Group I LD muscles and readings were continued at 2, 4, 6, 8, and 24 hr postmortem. Group II LD pH determinations were taken at 45

min, 2, 4, 6, 8, and 24 hr postmortem. Initial samples (1 hr or 45 min postmortem) were excised before electrical stimulation. The pH samples were removed from the LD opposite the fifth lumbar vertebrae with a 1.27 cm coring device. A 1 to 2 g muscle sample was blended with 10 ml of 5mM NaIAc in 150mM KCl (Bendall, 1973). The meat slurry pH was monitored on a Corning digital pH meter equipped with an Orion gel filled combination electrode.

Results and Discussion

Figure 5 shows the postmortem pH decline for the unstimulated LD controls (C) for both the continuous (CON) and intermittent (INT) ESHB treatments. The pH declines for both C groups were very similar, except at 4 hr postmortem.

Figure 6 shows the postmortem pH decline for the continuously (CON) electrically stimulated and hot-boned (ESHB) LD muscle and its control (C). CON-ESHB LD pH was 6.0 by approximately 2.7 hr postmortem and was at 5.7 by approximately 4.0 hr postmortem; whereas, its CON-C counterpart approached pH 6.0 at 4.0 hr after slaughter. At 24 hr postmortem, the pH decline of both CON-C and CON-ESHB treatments were essentially the same.

Nichols and Cross (1980) demonstrated similar results when electrically stimulating beef carcasses at 1 hr postmortem with approximately 200 V, 60 Hz AC for 2 min and hot boning at 1, 2, and 4 hr postmortem. They found that continuous stimulation of prerigor beef carcasses resulted in a LD pH of 6.0 in 2 hr postmortem.

Figure 5 - Longissimus dorsi pH declines for unstimulated controls (C) which correspond to the continuous (CON) and intermittent (INT) electrical stimulation treatments

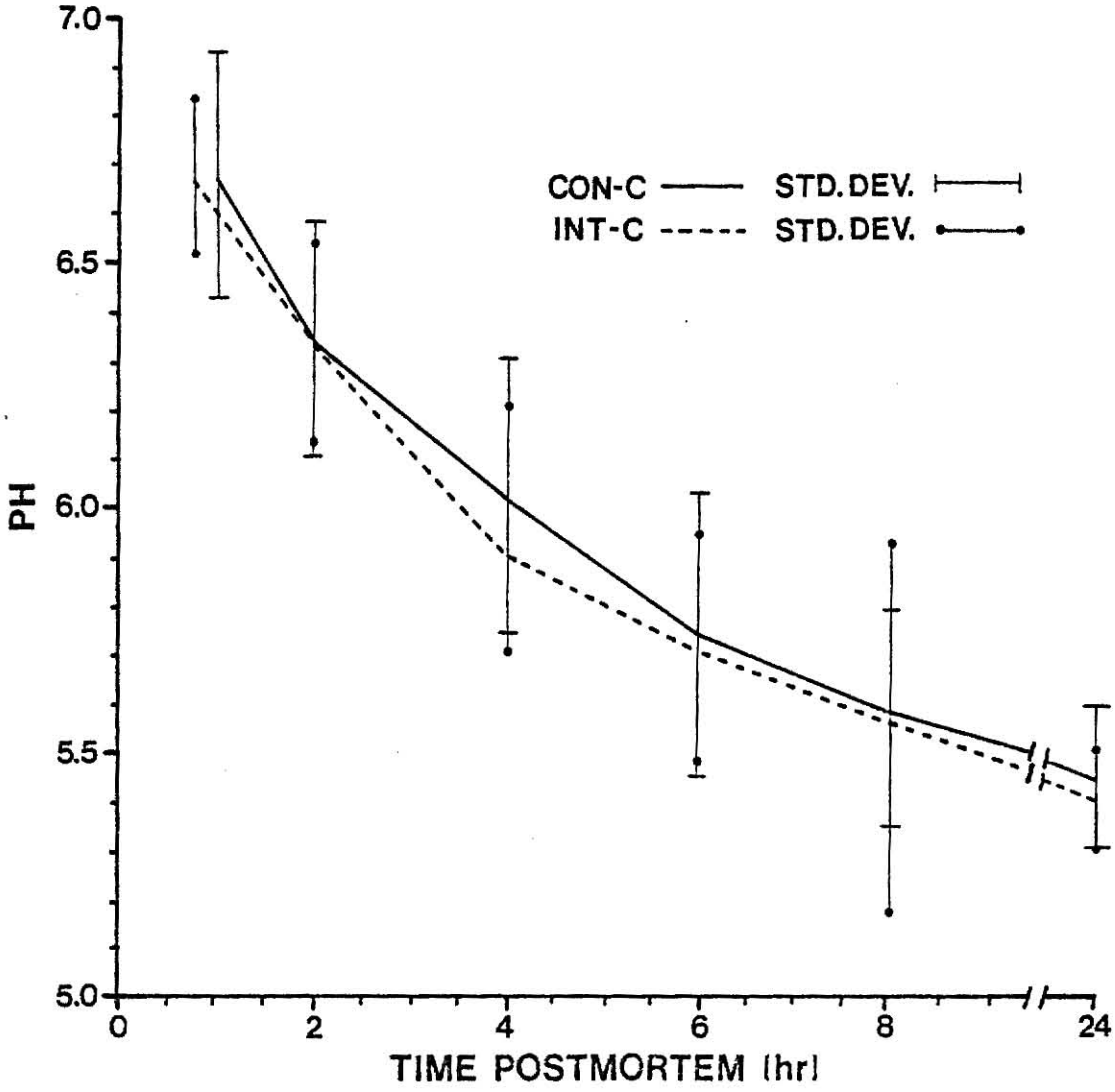
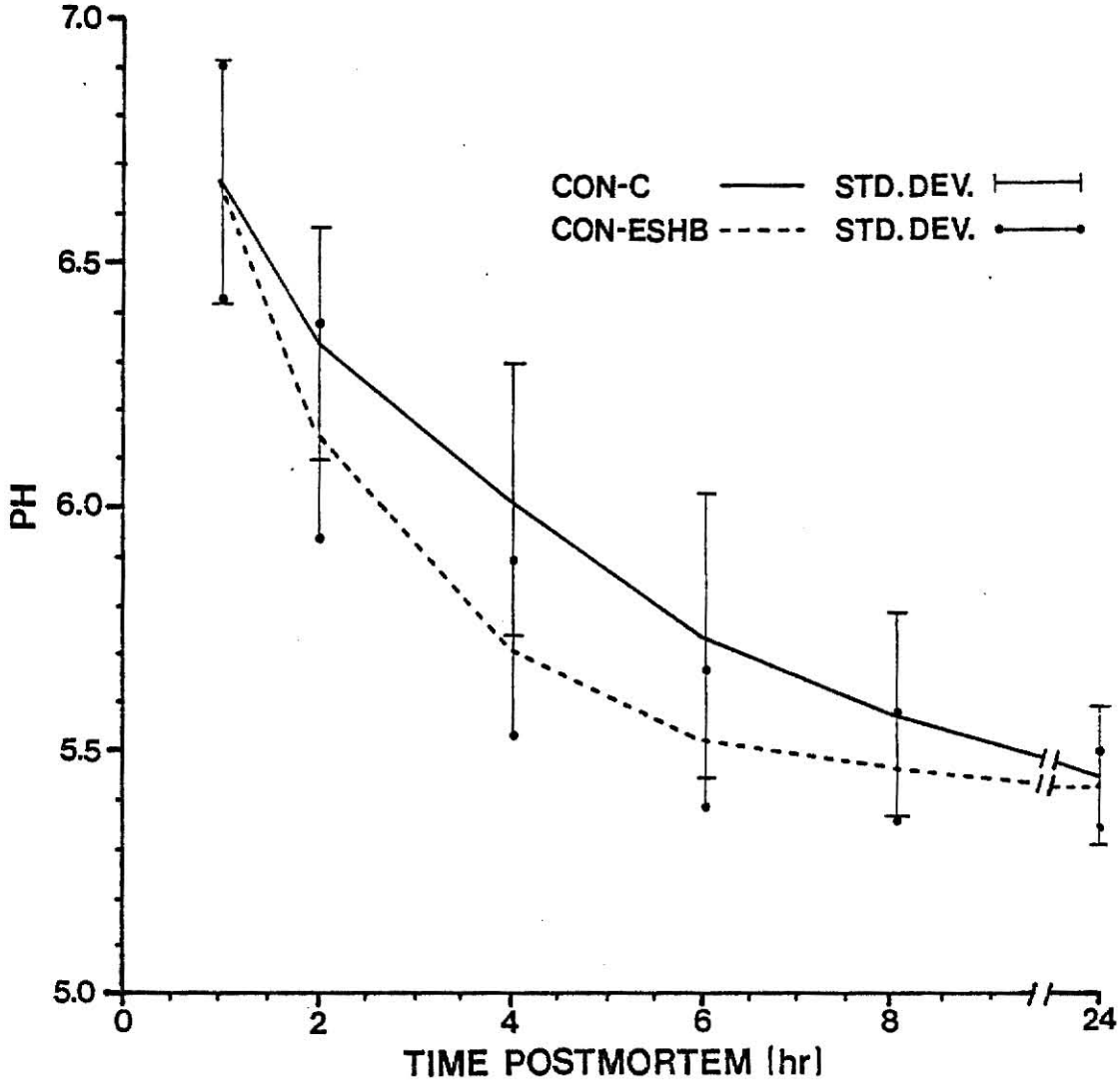

7.0
6.5
6.0
5.5
5.0
PH
CON-C STD.DEV.
INT-C STD.DEV.
0
2
4
6
8
24
TIME POSTMORTEM (hr)

Figure 6 - Postmortem pH declines for control (C) and continuously (CON) electrically stimulated and hot-boned (ESHB) *longissimus dorsi* muscle


7.0
6.5
6.0
5.5
5.0
PH
0
2
4
6
8
24
TIME POSTMORTEM (hr)
CON-C
STD. DEV.
CON-ESHB
STD. DEV.

Our findings at 24 hr postmortem agree with Taylor and Marshall (1980). Although the rate of pH decline was more rapid in the stimulated sides than in the control sides a similar ultimate pH was achieved at 24 hr postmortem.

Figure 7 shows the postmortem pH declines for the intermittent (INT) ESHB treatment and its control (C). At approximately 1.75 hr postmortem the INT-ESHB LD pH reached 6.0 while its INT-C counterpart did not attain this value until 3.5 hr postmortem.

Figure 8 illustrates the pH declines of the intermittent (INT) and continuous (CON) ESHB treatments. The INT-ESHB samples were at pH 6.0 in 1.75 hr postmortem while the CON-ESHB sample pH fell to 6.0 in 2.7 hr postmortem. At all times postmortem, INT-ESHB increased the rate of postmortem pH decline. However, INT-ESHB was administered at 45 min postmortem while CON-ESHB was not stimulated until 1 hr postmortem.

Contradictory to our findings, Devine (1976) noted that ES did increase muscle metabolism; however, the glycolytic rate was not altered by continuous or intermittent stimulation. Other researchers have found more dramatic drops in pH than we did (Chrystall and Hagyard, 1976; Bendall, 1976; Bendall et al., 1976). Chrystall and Hagyard (1976) stated that LD muscle pH in stimulated lamb carcasses fell to below 6.0 within 1 hr of slaughter compared with 14 hr for non-stimulated counterparts. However, stimulation was administered at 5 min postmortem compared with our 45 min and 1 hr postmortem stimulation times. The pH declines were similar in electrically stimulated lamb (Bendall, 1976) and beef (Bendall et al., 1976).

Figure 7 - Postmortem pH declines for control (C) and intermittently (INT) electrically stimulated and hot-boned (ESHB) *longissimus dorsi* muscle

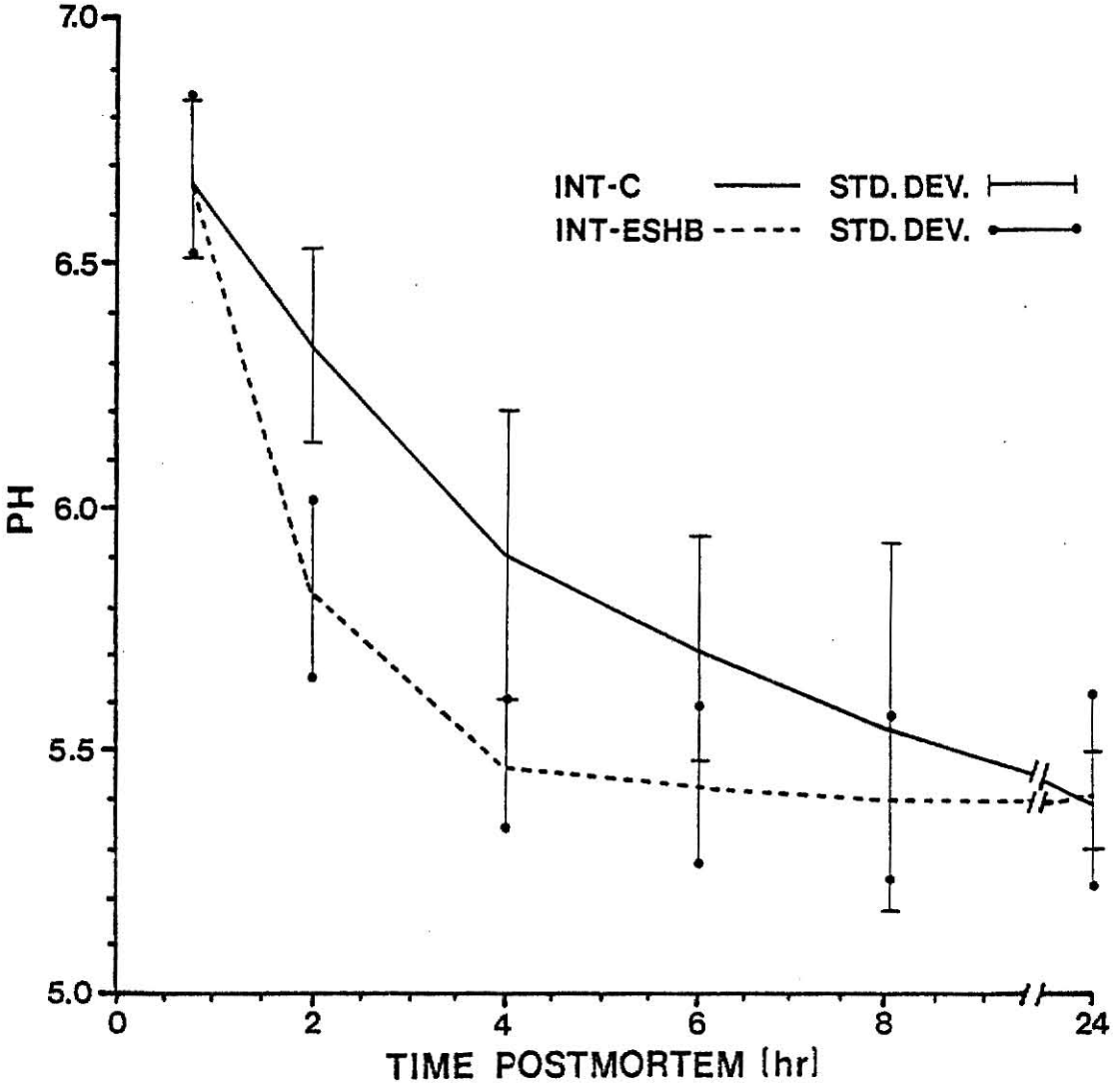
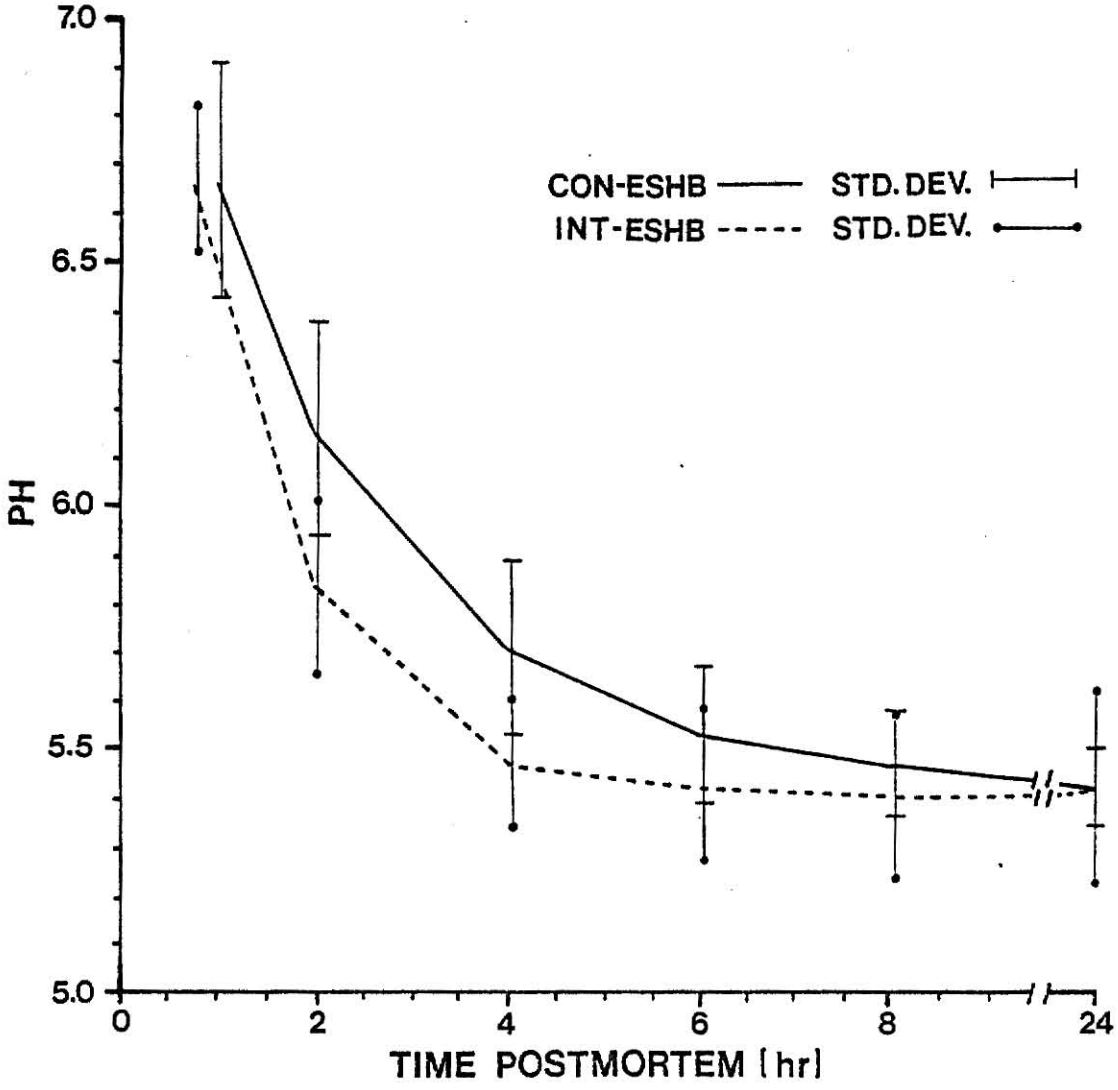

7.0
6.5
6.0
5.5
5.0
PH
INT-C
STD. DEV.
INT-ESHB
STD. DEV.
0
2
4
6
8
24
TIME POSTMORTEM [hr]

Figure 8 - Postmortem pH declines for continuous (CON) and intermittent (INT) electrically stimulated and hot-boned (ESHB) *longissimus dorsi* muscle


7.0
6.5
6.0
5.5
5.0
PH
0
2
4
6
8
24
TIME POSTMORTEM [hr]
CON-ESHB
STD. DEV.
INT-ESHB
STD. DEV.

In both studies muscles in the forelimb, back, and thigh reached pH 6.0 in 1 to 1.5 hr postmortem when electrically stimulated 50 min postmortem with 700 V, 25 Hz for 2 min.

Summary

Even though both continuous and intermittent electrical stimulation were successful in accelerating postmortem pH decline in the LD muscle, intermittent stimulation decreased the muscle pH at a faster rate at all times postmortem. Intermittent stimulation at 45 min postmortem appears to be a more effective method of accelerating postmortem pH decline in the LD muscle when compared with continuous stimulation at 1 hr postmortem. Therefore, if electrical stimulation is used in conjunction with HB of beef carcasses, intermittent stimulation at 45 min postmortem may prove more beneficial than continuous stimulation at 1 hr postmortem.

REFERENCES

Bendall, J.R. 1973. In "Structure and Function of Muscle." Vol. 2. p. 243. Academic Press, New York.

Bendall, J.R. 1976. Electrical stimulation of rabbit and lamb carcasses. J. Sci. Fd. Agric. 27:819.

Bendall, J.R., Ketteridge, C.C., and George, A.R. 1976. The electrical stimulation of beef carcasses. J. Sci. Fd. Agric. 27:1123.

Bendall, J.R. and Rhodes, D.N. 1976. Electrical stimulation of the beef carcass and its practical application. Proceedings of 22nd Meat Res. Conf. Vol. I. Sweden.

Carse, W.A. 1973. Meat quality and the acceleration of postmortem glycolysis by electrical stimulation. J. Food Technol. 8:163.

Chrystall, B.B. and Hagyard, C.J. 1975. Accelerated conditioning of lamb. N.Z. J. Agric. Res. June:7.

Chrystall, B.B. and Hagyard, C.J. 1976. Electrical stimulation and lamb tenderness. N.Z. J. Agric. Res. 19:7.

Corte, O.O., Cia, G., Picchi, V., Procknor, M.L.S.C., and Delazari, I. 1980. Electrical stimulation and hot boning of beef carcasses associated with chilling or freezing. Proceedings of 26th European Meeting of Meat Research Workers. Colorado Springs, Colorado. 2:53.

Davey, C.L., Gilbert, K.V., and Carse, W.A. 1976. Carcass electrical stimulation to prevent cold shortening toughness in beef. N.Z. J. Agric. Res. 19:13.

DeFremery, D. and Pool, M.F. 1960. Biochemistry of chicken muscle as related to rigor mortis and tenderization. Food Res. 25:73.

Devine, C.E. 1976. Accelerated conditioning of meat. Proceedings of 18th Meat Ind. Res. Conf., MIRINZ. Hamilton, New Zealand. 10.

Falk, S.N. and Henrickson, R.L. 1974. Feasibility of hot boning the bovine carcass. Animal Science Research. Oklahoma Agric. Exp. Station. 145.

Falk, S.N., Henrickson, R.L., and Morrison, R.D. 1975. Effect of boning beef carcasses prior to chilling on meat tenderness. J. Food Sci. 40:1075.

Gilbert, K.V. and Davey, C.L. 1976. Carcass electrical stimulation and early boning of beef. N.Z. J. Agric. Res. 19:429.

Gilbert, K.V., Davey, C.L., and Newton, K.G. 1977. Electrical stimulation and the hot boning of beef. N.Z. J. Agric. Res. 20:139.

Kastner, C.L., Henrickson, R.L., and Morrison, R.D. 1973. Characteristics of hot-boned bovine muscle. J. Anim. Sci. 36:484.

Kastner, C.L. and Russell, T.S. 1975. Characteristics of conventionally and hot-boned bovine muscle excised at various conditioning periods. J. Food Sci. 40:747.

Kastner, C.L., Sullivan, D.P., Ayaz, M., and Russell, T.S. 1976. Further evaluation of conventional and hot-boned bovine longissimus dorsi muscle excised at various conditioning periods. J. Food Sci. 41:97.

Locker, R.H. and Hagyard, C.J. 1963. A cold shortening effect in beef muscles. J. Sci. Fd. Agric. 14:787.

McCollum, P.D. and Henrickson, R.L. 1977. The effect of electrical stimulation on the rate of post-mortem glycolysis on some bovine muscles. J. Food Quality. 1:15.

Nichols, J.E. and Cross, H.R. 1980. Effects of electrical stimulation and early postmortem muscle excision on pH decline, sarcomere length and color in beef muscles. J. Food Prot. 43:514.

Schmidt, G.R. and Gilbert, K.V. 1970. The effect of muscle excision before the onset of rigor mortis on the palatability of beef. J. Food Technol. 5:331.

Schmidt, G.R. and Keman, S. 1974. Hot boning and vacuum packaging of eight major bovine muscles. J. Food Sci. 39:140.

Seideman, S.C., Smith, G.C., Dutson, T.R., and Carpenter, Z.L. 1979. Physical, chemical and palatability traits of electrically stimulated, hot-boned, vacuum-packaged beef. J. Food Prot. 42:651.

Taylor, D.G. and Marshall, A.R. 1980. Low voltage electrical stimulation of beef carcasses. J. Food Sci. 45:144.

Will, P.A., Henrickson, R.L., Morrison, R.D., and Odell, G.V. 1979. Effect of electrical stimulation on ATP depletion and sarcomere length in delay-chilled bovine muscle. J. Food Sci. 44:1646.

Chapter V

APPENDIX

Table 4 - Analysis of variance for Warner-Bratzler shear force; taste panel variables; percentage thaw, cooking, and combined losses for the longissimus dorsi muscle

Source of Variation	Warner-Bratzler Shear Force			Flavor Intensity			Juiciness		
	D.F.	M.S.	F	D.F.	M.S.	F	D.F.	M.S.	F
TRT	3	--	17.59**	3	--	1.44	3	--	0.30
SLGP	3	--	5.16**	3	--	3.11*	3	--	5.58**
Animal (SLGP)	44	--	1.88*	44	--	1.45	44	--	1.72*
Error (a)	45	1.2731	--	45	0.0585	--	45	0.1454	--
FRFZ	1	--	91.23**	1	--	1.45	1	--	0.11
TRT*FRFZ	3	--	4.34**	3	--	2.19	3	--	2.93*
Error (b)	92	0.9176	--	92	0.0864	--	92	0.2315	--

Table 4 (continued)

Source of Variation	Myofibrillar Tenderness			Connective Tissue Amount			Overall Tenderness		
	D.F.	M.S.	F	D.F.	M.S.	F	D.F.	M.S.	F
TRT	3	--	16.39**	3	--	10.33**	3	--	21.07**
SLGP	3	--	1.49	3	--	7.45**	3	--	1.64
Animal (SLGP)	44	--	1.19	44	--	1.20	44	--	1.35
Error (a)	45	0.2628	--	45	0.1180	--	45	0.2301	--
FRFZ	1	--	52.22**	1	--	16.33**	1	--	49.44**
TRT*FRFZ	3	--	9.79**	3	--	3.64*	3	--	11.10**
Error (b)	92	0.2855	--	92	0.0911	--	92	0.2181	--

Table 4 (continued)

Source of Variation	Thaw Loss			Cooking Loss			Combined Loss		
	D.F.	M.S.	F	D.F.	M.S.	F	D.F.	M.S.	F
TRT	3	--	1.06	3	--	0.18	3	--	0.31
SLGP	3	--	50.70**	3	--	66.70**	3	--	91.50**
Animal (SLGP)	44	--	1.30	44	--	1.01	44	--	1.23
Error (a)	45	0.8375	--	45	9.9942	--	45	8.8940	--
FRFZ	1	--	30.07**	1	--	8.78**	1	--	20.39**
TRT*FRFZ	3	--	2.02	3	--	2.00	3	--	2.87*
Error (b)	92	2.0977	--	92	17.9419	--	92	15.2710	--

TRT - carcass treatment
SLGP - slaughter group
FRFZ - fresh-frozen storage treatment
Error (a) - between carcass treatment error (between sides)
Error (b) - between fresh and frozen storage treatment error (within sides)
** $P < 0.01$
* $P < 0.05$

Table 5 - Analysis of variance for Warner-Bratzler shear force; taste panel variables; percentage thaw, cooking, and combined losses for the semimembranosus muscle

Source of Variation	Warner-Bratzler Shear Force			Flavor Intensity			Juiciness		
	D.F.	M.S.	F	D.F.	M.S.	F	D.F.	M.S.	F
TRT	3	--	7.59**	3	--	1.24	3	--	0.08
SLGP	3	--	7.32**	3	--	4.97**	3	--	8.02**
Animal (SLGP)	44	--	1.43	44	--	1.20	44	--	1.34
Error (a)	45	1.8297	--	45	0.0345	--	45	0.0967	--
FRFZ	1	--	1.28	1	--	2.63	1	--	2.08
TRT*FRFZ	3	--	1.61	3	--	0.32	3	--	0.55
Error (b)	92	1.5154	--	92	0.0475	--	92	0.1601	--

Table 5 (continued)

Source of Variation	Myofibrillar Tenderness			Connective Tissue Amount			Overall Tenderness		
	D.F.	M.S.	F	D.F.	M.S.	F	D.F.	M.S.	F
TRT	3	--	13.19**	3	--	7.37**	3	--	16.98**
SLGP	3	--	18.95**	3	--	49.58**	3	--	32.40**
Animal (SLGP)	44	--	2.29**	44	--	5.61**	44	--	2.65**
Error (a)	45	0.0808	--	45	0.0284	--	45	0.0495	--
FRFZ	1	--	35.99**	1	--	93.04**	1	--	70.56**
TRT*FRFZ	3	--	2.73*	3	--	0.86	3	--	0.64
Error (b)	92	0.1436	--	92	0.1221	--	92	0.1390	--

Table 5 (continued)

Source of Variation	Thaw Loss			Cooking Loss			Combined Loss		
	D.F.	M.S.	F	D.F.	M.S.	F	D.F.	M.S.	F
TRT	3	--	5.06**	3	--	1.47	3	--	2.40
SLGP	3	--	70.09**	3	--	37.00**	3	--	57.94**
Animal (SLGP)	44	--	1.01	44	--	1.55	44	--	1.67*
Error (a)	45	0.6881	--	45	10.7661	--	45	8.9276	--
FRFZ	1	--	0.02	1	--	1.07	1	--	0.36
TRT*FRFZ	3	--	0.73	3	--	4.10**	3	--	2.40
Error (b)	92	1.3821	--	92	15.9848	--	92	12.8527	--

TRT - carcass treatment
SLGP - slaughter group
FRFZ - fresh-frozen storage treatment
Error (a) - between carcass treatment error (between sides)
Error (b) - between fresh and frozen storage treatment error (within sides)
** $P < 0.01$
* $P < 0.05$

Table 6 - Standard error, pooled t value, and LSD formulas

Comparison of carcass treatments within fresh or frozen storage treatments

$$\text{Std. Error} = \sqrt{\frac{2(MSE(a) + MSE(b))}{2 \times 12}}$$

$$t^* = \frac{t_{(45\ d.f.)}\ (MSE(a)) + t_{(92\ d.f.)}\ (MSE(b))}{MSE(a) + MSE(b)}$$

$$LSD = t^*\ (\text{Std. error})$$

Comparison of fresh and frozen storage by carcass treatment

$$LSD = t_{(92\ d.f.)}\ (\sqrt{MSE(b)})\ (\sqrt{2/2 \times 12})$$

MSE(a) - mean square error between carcass treatments (between sides)
MSE(b) - mean square error between fresh and frozen storage treatments (within sides)
t^* - calculated pooled t value
LSD - least significant difference

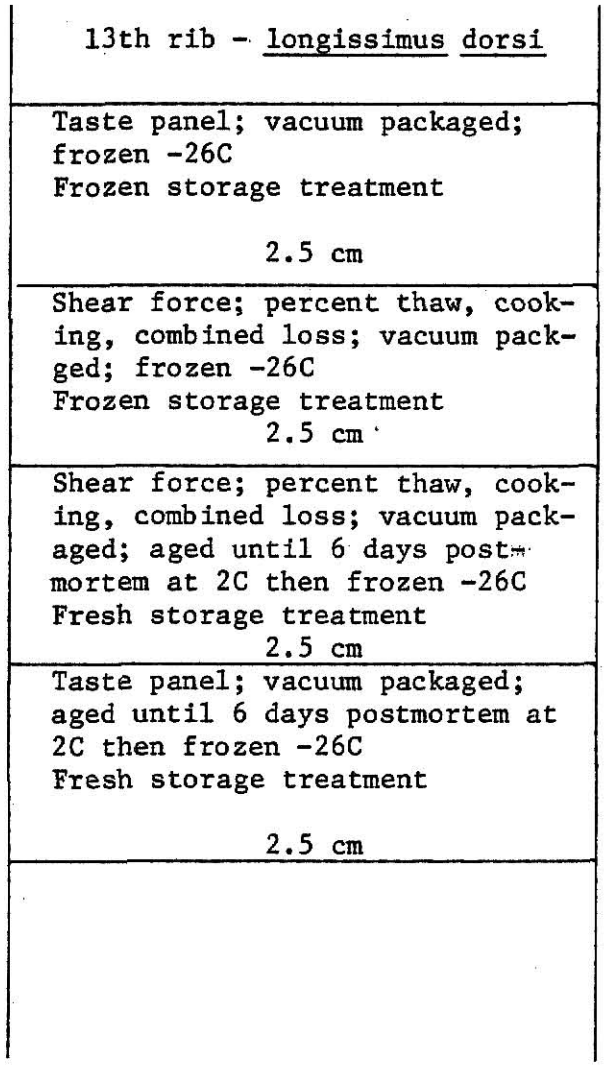
Table 7 - Mean Square Error[a] Terms used in Calculating Standard Deviations[b] of Carcass Treatment Means in Tables 1, 2, and 3 by Variable, Muscle, and Storage Treatment

	Longissimus dorsi		Semimembranosus	
Variable	Fresh	Frozen	Fresh	Frozen
Taste Panel				
Flavor Intensity	0.1141	0.0877	0.0500	0.0517
Juiciness	0.2593	0.2364	0.1100	0.1890
Myofibrillar Tenderness	0.2251	0.6410	0.1121	0.1683
Connective Tissue Amount	0.1393	0.1866	0.1229	0.0633
Overall Tenderness	0.2061	0.4821	0.1151	0.1216
Warner-Bratzler Shear Force	0.9561	2.4504	1.7250	3.2607
Cooking Loss Analyses				
Thaw Loss	1.5244	1.7815	1.1257	1.7569
Cooking Loss	22.3800	18.0566	20.3185	15.8126
Combined Loss	18.5946	16.4974	16.3077	15.2637

[a] Mean square error = MSE

[b] Standard Deviation = $\sqrt{MSE/24}$

Anterior End of Longissimus dorsi or Proximal End of Semimembranosus



Posterior End of Longissimus dorsi or Distal End of Semimembranosus

Figure 9 - Sampling arrangement for test muscles

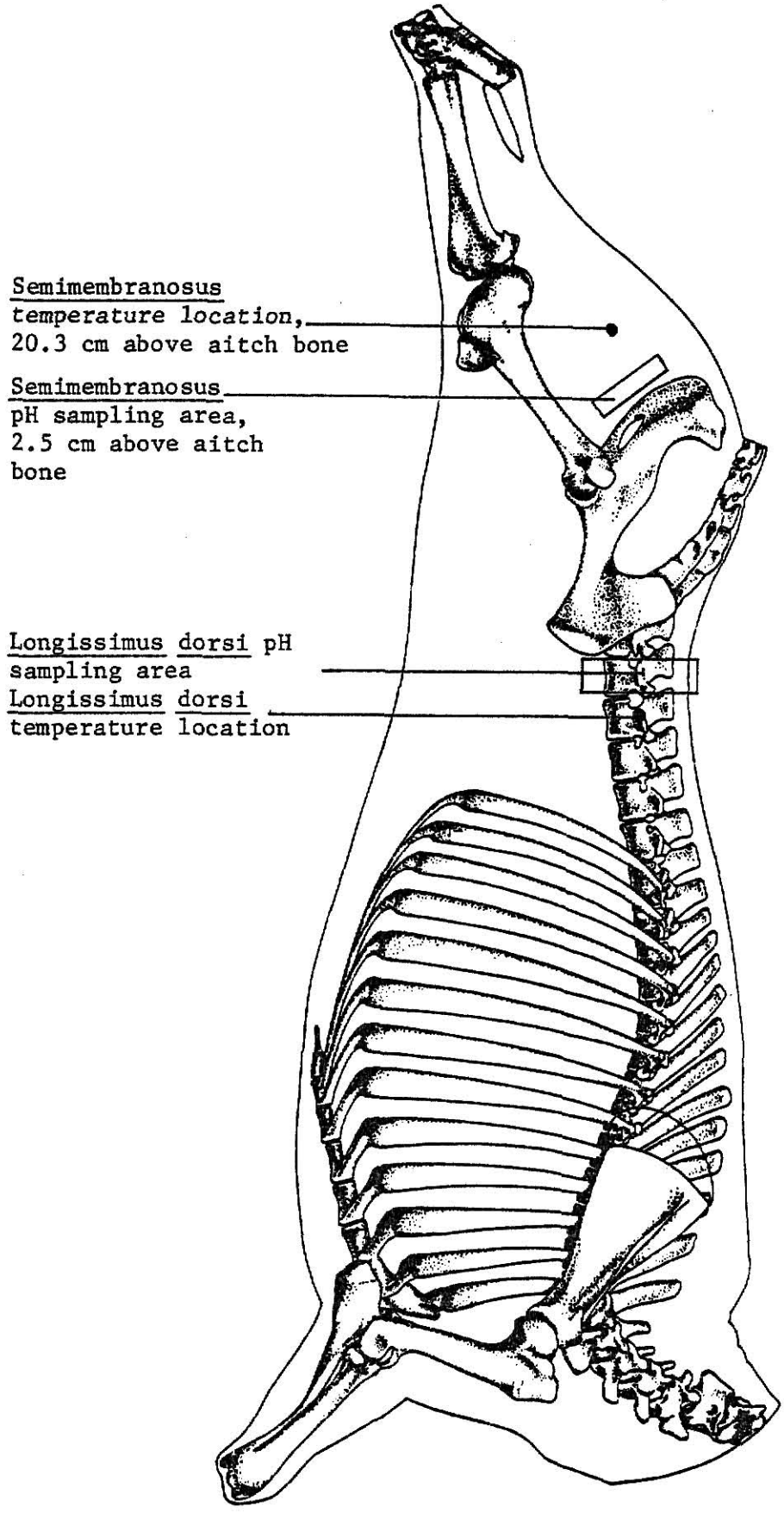


Figure 10 - Temperature and pH sampling locations

Judge _____ Date _____ Code _____

Sample Number	Flavor Intensity	Juiciness	Myofibrillar Tenderness	Connective Tissue Amount	Overall Tenderness	Comments
A						
B						
C						
D						
E						
F						
G						
H						

Flavor intensity	Juiciness	Myofibrillar tenderness	Connective tissue amount	Overall tenderness
8 Extremely intense	8 Extremely juicy	8 Extremely tender	8 None	8 Extremely tender
7 Very intense	7 Very juicy	7 Very tender	7 Practically none	7 Very tender
6 Moderately intense	6 Moderately juicy	6 Moderately tender	6 Traces	6 Moderately tender
5 Slightly intense	5 Slightly juicy	5 Slightly tender	5 Slight	5 Slightly tender
4 Slightly bland	4 Slightly dry	4 Slightly tough	4 Moderate	4 Slightly tough
3 Moderately bland	3 Moderately dry	3 Moderately tough	3 Slightly abundant	3 Moderately tough
2 Very bland	2 Very dry	2 Very tough	2 Moderately abundant	2 Very tough
1 Extremely bland	1 Extremely dry	1 Extremely tough	1 Abundant	1 Extremely tough

Figure 11 - Taste panel evaluation sheet for beef palatability

EFFECTS OF BEEF CARCASS ELECTRICAL STIMULATION AND HOT BONING ON MUSCLE pH DECLINE RATES AND SENSORY CHARACTERISTICS OF FRESH AND FROZEN STEAKS

by

JOY EUGENIA BOWLES

B.S., University of Tennessee, 1979

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

FOOD SCIENCE

Department of Animal Sciences and Industry

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1981

Ninety-six sides from 48 U.S.D.A. Good and Choice grade carcasses were used to study the effects of hot boning (HB), electrical stimulation (ES), a combination of ES and HB (ESHB), and steak storage treatments on pH and temperature declines, percentage thaw and cooking losses, Warner-Bratzler shear force, and sensory panel ratings for samples from longissimus dorsi (LD) and semimembranosus (SM) muscles. The pH and temperature data were monitored at 45 min (pH), 2, 4, 6, 8, 10 (temperature), and 24 hr postmortem. Steak storage treatments were fresh (stored until 6 days postmortem at 2C then frozen at -26C) and frozen (frozen 24 or 48 hr postmortem and stored at -26C). Data were analyzed using analysis of variance. To determine differences between means, the least significant difference method was utilized. In both storage treatments for the LD and SM steaks, ES did not improve taste panel ratings or consistently lower Warner-Bratzler shear force values when compared to control (C) counterparts. When comparing HB to C for fresh and frozen LD and SM steaks, HB generally decreased tenderness, but no differences ($P > 0.05$) existed between fresh stored SM C and HB steaks. ESHB LD and SM samples were comparable ($P > 0.05$) in tenderness to their C counterparts as evaluated by taste panel and Warner-Bratzler shear force ratings regardless of the steak storage treatment. Therefore, ES alleviated any toughening effects of HB. When taste panel and shear force differences ($P < 0.05$) between the fresh and frozen storage treatments existed, the LD steaks responded better to fresh storage. The SM taste panel ratings favored frozen storage, but SM shear force mean comparisons did not support these observations. When statistical

differences existed between fresh and frozen storage for percentage thaw, cooking, and combined loss means, the fresh system was favored. Few differences existed between C, ES, HB, and ESHB treatments for thaw, cooking, and combined losses.

In a second study, two groups of crossbred steers were slaughtered and sides were either electrically stimulated and hot boned or served as controls. The experiment was designed to determine which method of ES (continuous or intermittent) combined with HB induced the most rapid postmortem pH decline and onset of rigor mortis. Forty-six sides were electrically stimulated at 1 hr postmortem with 400 volts of continuous, 60 hertz alternating current. Approximately 1 amp was delivered through the carcass for 2 min. At 2 hr postmortem the LD was hot boned. Twenty-four sides were electrically stimulated and hot boned similarly, except ES was administered at 45 min postmortem and the stimulation parameters were altered to incorporate an intermittent stimulation. Intermittent stimulation lasted 2 min and consisted of a series of 1.6 sec "on" pulses with 0.8 sec between pulses. The pH readings were taken prior to stimulation (45 min or 1 hr), 2, 4, 6, 8, and 24 hr postmortem.

Continuous and intermittent ES were successful in accelerating postmortem pH decline in the LD muscle; however, intermittent stimulation gave the lowest muscle pH values at all postmortem times.