EFFECTS OF ELECTRICAL STIMULATION, HOT BONING AND CHILLING ON BULL SEMIMEMBRANOSUS MUSCLE

by

SUSAN DUDLEY SHIVAS

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Approved by:

Curtis L. Kastner

Major Professor

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Chapter I

GENERAL INTRODUCTION

The current predominant industry practice of chilling beef carcasses before processing was initiated after the development of refrigeration. Traditional meat chilling, begun after carcass dressing, retards microbial activity and firms fat and lean for subsequent grading and fabrication. Chilled carcasses may be shipped as quarters or "centrally processed" into primals, subprimals or even retail cuts before boxing and shipping. Currently, the beef industry transports most meat as vacuum packaged, boxed primals and subprimals. Boxed beef is more economically feasible than quartered beef as it decreases transportation costs and increases shelf life. At the retail level, boxed or carcass beef is further processed into retail cuts. Excess bone and fat are then removed and processed, usually by rendering (Kastner, 1982b).

Hot processing of meat is not a recent development. Before refrigeration was developed, countries in hot and temperate climates hot-processed meat. Even today, some areas of the world lack refrigeration for meat processing facilities and must practice hot processing. The original justification for hot-processing systems was reduction in refrigeration energy requirements since excess bone and fat were not chilled on the carcass. However, studies have shown other advantages of hot processing (Kastner, 1977; Cuthbertson, 1979; Erickson et al.,

1980). With renewed interest in hot processing, a variety of descriptive terms have been coined: hot boning, pre-rigor excision, hot cutting, accelerated processing and high temperature processing. All refer to the practice of removal, and possible further processing of individual muscles or muscle systems from carcasses before conventional chilling. The meat may be pre- or post-rigor, depending on the biochemical state of the muscle upon excision (Kastner, 1982a).

Muscle processed in the pre-rigor state can be tough due to detachment from skeletal restraints and/or more rapid chilling of the muscle (Schmidt and Gilbert, 1970). Locker (1960) reported sudden shortening upon muscle excision and further slower shortening upon rigor development in pre-rigor excised muscles. The degree of muscle shortening influenced toughness. Ramsbottom and Strandine (1949) reported beef boned at 2 hr postmortem and chilled as tougher than beef chilled as carcasses. Temperature exerts an influence on the degree of shortening of pre-rigor excised muscles. Minimal muscle fiber shortening occurs in the temperature range of 14 to 19°C. At colder temperatures (less than 14°C), muscles shorten more; at 0°C, muscle shortening of as much as 50% of the resting length can occur. Cold shortening describes the additional fiber length decrease occurring at temperatures below 14°C (Locker and Hagyard, 1963). Additionally, shortening reduces the effectiveness of aging (Davey et al., 1967).

Electrical stimulation soon after slaughter reduces the effects of pre-rigor excision and cold shortening in muscle. This postmortem processing practice accelerates glycolysis and the onset of rigor mortis (Carse, 1973; Davey et al., 1976). Additionally, electrical

stimulation may have other modes of tenderization besides the prevention of cold shortening. Increased physical disruption of tissue, increased lysosomal enzyme activity and decreased thermal shrinkage temperature of beef connective tissue have been proposed to occur in electrically stimulated meat (Dutson et al., 1980; Savell et al., 1978a; Judge et al., 1980). Using electrical stimulation in combination with hot boning should allow for earlier boning, since the rate of rigor mortis onset is accelerated. Electrical stimulation may eliminate some tenderness problems associated with cutting and rapid chilling or freezing of hot processed muscle (Kastner, 1982a).

The objective of the study, as described in Chapter III, was to evaluate the palatability and cooking loss attributes of semimembranosus samples from electrically stimulated and hot-boned young bull carcasses when those muscles were subjected to two chilling conditions.

Chapter II

GENERAL LITERATURE REVIEW

Hot Boning

Hot boning (HB) implies that carcasses are processed soon after slaughter and before conventional chilling. HB systems fit well into the current concept of centralized processing and boxed beef marketing (Erickson et al., 1980). Several researchers have outlined potential economic advantages and disadvantages of HB (Henrickson, 1975: Kastner, 1977; Dvorak, 1979; Cuthbertson, 1979; Erickson et al., 1980; Henrickson, 1981).

Renewed interest in HB has been spurred by increasing energy costs and pressure for energy conservation. The meat industry is one of the largest consumers of energy. Henrickson (1975) estimated that HB of a 600 lb. Choice beef carcass could result in 30% reduction in energy requirements per carcass and 78% refrigerated space saving when compared to conventional beef processing. Erickson et al. (1980) found similar energy reductions (32%) with HB and attributed a significant part of the savings to removal of the shroud load with hot boning. HB also reduces the amount of product that must be chilled because excess fat and bone are removed. An in-plant study has reported overall space savings of 50% (Dvorak, 1979). Buchter (1982), in a cooperative study with a Danish meat plant, reported an estimated 50% reduction in

chilling room space. Additionally, the plant was able to utilize chillers in rooms with lower ceilings for chilling, because carcasses did not have to be accommodated.

Henrickson (1981) reported one source of energy savings for the meat industry as reduced transportation costs for HB beef as compared with beef carcasses. These savings are realized with both hot-boned and conventionally centralized processed boxed beef. However, more savings are possible with HB beef since only muscle and little fat is transported, and the conventional centralized processed beef comparison included bone plus non-trimmable fat.

Hot boning may reduce labor, material and equipment costs (Kastner, 1977; Cuthbertson, 1979; Erickson et al., 1980; Buchter, 1982). This technique eliminates the need for the labor intensive and costly operations of neck pinning, scribing and shrouding. A Dvorak (1979) study showed a 25% labor reduction for HB beef as compared with conventionally processed beef. Labor reductions are further attributed to increased worker efficiency. During hot boning, hands stay warm and warm muscles are more pliable and removable. One plant reported 10 to 15% less cutting-line labor for HB as compared with conventional processing (Buchter, 1982).

Other savings could be realized from increased product flow-through, partially due to decreased chilling time and increased labor efficiency (Kastner, 1977). Hot boning readily lends itself to mechanical handling of boxed cartons which contain warm primals or subprimals (McLeod et al., 1973). Cuthbertson (1979) suggested that hot-processing presents an opportunity to mold cuts. Apple and Terlizzi (1982) reported that the

adhesive nature of HB meat made it difficult to load the vacuum package. However, by using oversize packaging materials and drawing higher vacuum levels, air pockets and moisture condensation may be avoided. A Danish in-plant study reported improved appearance of vacuum packaged hot-boned muscles due to meat molding (Buchter, 1982).

Appearance of HB meat is improved by more uniform color of the muscle, less staining of the fat and less drip in the vacuum bags (Cross et al., 1979; Cuthbertson, 1979; Buchter, 1977, 1982; Taylor et al., 1980). With conventional processing (cold boning) lack of muscle color uniformity has been attributed to uneven muscle cooling within the carcass. Hot-boned muscle has more uniform cooling rates than muscles chilled in the carcass, so color is more uniform, especially with thick muscles where cooling is slower (Cuthbertson, 1979). Taylor et al. (1980) reported color differences between the inner and outer portions of cold-boned semimembranosus (SM) muscles, while hot-boned SM muscles had minimal differences.

Improvement in meat yield has been cited as a major advantage of hot boning (Cuthbertson, 1979), as yield is increased by less evaporative losses from the meat surface during chilling. Vacuum packaging soon after muscle excision and quicker chilling of HB muscle can produce increased yields over cold boning. Several researchers have reported reductions in evaporative losses of HB muscle and/or increased yields when compared with conventional processing (Kastner et al., 1973; Follett et al., 1974; Dvorak, 1979; Corte et al., 1980; Erickson et al., 1980; Taylor et al., 1980; Buchter, 1982; Chrystall, 1982). Still others have found no difference in meat yields with hot boning techniques (Schmidt and Keeman, 1974; Kastner et al., 1976).

One major hindrance in the U.S. meat industry's acceptance of hot boning of beef and lamb is the inability to quality and yield grade carcasses (Kastner, 1977). Alternate methods of measuring carcass characteristics would have to be employed. Cross et al. (1981) suggested three approaches to remedying this problem. A short-term approach utilizes traits that are measurable in hot, unribbed carcasses which are closely related to presently measured traits. Some traits that may be employed are feathering, flank streaking, flank color, diaphragm muscle marbling, bone maturity and carcass finish. More long-term solutions are instrumental grading and carcass certification.

Another disadvantage of HB muscle is an unconventional shape as compared with cold-boned meat. In vacuum bags, hot-boned meat takes the shape of the vacuum package (Cuthbertson, 1982). Bowling (1981) reported that shape distortion could present problems for processors in the H.R.I. trade. However, meat molding could be advantageously employed. A Danish system uses Multivac® thermoforming to mold HB muscle (Buchter, 1982). The British have used heat-shrunk Cryovac BB1 bags or nylon/polyethylene bags for molding hot-boned cuts (Cuthbertson, 1982).

Hot boning requires greater hygiene as the warm moist surfaces could facilitate bacterial growth (Cuthbertson, 1979; Buchter, 1982; Oblinger, 1982). Buchter (1982) cautioned that greater care, to prevent carcass and cutting contamination, must be exercised with HB. Fung et al. (1980) found early postmortem chilling rate important in controlling microbial growth, especially with boxed HB cuts. In a later study, Fung et al. (1981) examined the effects of initial chilling

to 21°C in 3, 5, 9 or 12 hr on the microbial counts of HB beef after vacuum package storage for 14 or 21 days at 2.2°C and display for 3 days. These researchers found hot-boned beef chilled to 21°C by 9 hr or less after HB to be of acceptable microbial quality. Walker (1982) reported that conventional Australian cooling systems do not chill hot-boned meat quickly enough to insure product quality.

Other potential disadvantages of hot-processing include difficulty of trimming hot fat (Cuthbertson, 1979; Bowling, 1981); difficulty of timing slaughter, boning and fabrication operations; acceptance in conventionally designed plants (Cuthbertson, 1979; Buchter, 1982) and the inability to recognize dark cutting beef soon post slaughter (Buchter, 1982). Also, tenderness of HB muscle has been a major concern. Generally, a hot-boned product of acceptable tenderness can be produced if (1) cuts are conditioned at elevated temperatures after boning, (2) cuts are aged at refrigeration temperatures, (3) carcasses are conditioned at elevated temperatures before boning and/or (4) carcasses are electrically stimulated before boning.

The toughness of hot-boned beef may be attributed to pre-rigor muscle excision, cold shortening or, if the muscle is frozen, thaw rigor (Locker, 1960; Locker and Hagyard, 1963; Marsh and Leet, 1966; Marsh et al., 1968; Marsh, 1972, 1977; Davey and Gilbert, 1974; Chrystall, 1976). Of the two muscle tissue affectors of tenderness, collagen and myofibrillar proteins, the latter is of the most concern in hot-boned, pre-rigor muscle. Locker (1960) stated that muscle shortening occurs upon excision of pre-rigor muscle and further, slighter shortening occurs as the muscle enters rigor. By monitoring

the onset of rigor mortis, the optimal time, temperature potential for cold shortening in hot-boned muscle can be evaluated.

Post-slaughter inter-relationships between rigor onset and muscle pH, adenosine triphosphate (ATP) and creatine phosphate (CP) levels have been determined. After slaughter, muscle pH exhibits a steady decline; CP is exhausted within a few hr in an effort to keep ATP furnished to the muscle. While CP is in adequate supply, muscle actomyosin cross-bridge formation is minimal. However, when CP is depleted, the ATP level in the muscle starts to rapidly decline, actomyosin crossbridges are formed, the muscle loses extensibility and rigor is established (Marsh, 1981). Anaerobic glycolysis causes a steady accumulation of lactic acid until the muscle is in full rigor. Because anaerobic glycolysis cannot meet the muscle's demand for ATP, the ATP level steadily declines as lactic acid accumulates (Marsh, 1977). Therefore, by monitoring pH, the onset of rigor mortis can be determined (Forrest et al., 1975).

Locker and Hagyard (1963) studied the effects of time and temperature on cold shortening in several beef and rabbit muscles. In beef, greater shortening occurred at 2°C than at 37°C; the temperature region of 14 to 19°C produced the least amount of shortening. By holding muscles at 25°C for 11 hr before chilling at 2°C, shortening was reduced as compared with delaying chilling for 1.5, 7 or 9 hr. Different beef muscles responded differently to the 2°C chilling. Rabbit muscle showed no cold-induced shortening.

Calcium concentration increase was found to be responsible for cold shortening in beef muscle (Davey and Gilbert, 1974). As muscle

temperature was lowered, the ability of the calcium pump to remove calcium from the myofibril back into the sarcoplasmic reticulum was lessened. Cold shortening occurred when the myofibrillar calcium concentration increased 30 to 40 times the original concentration due to the lowering of muscle temperatures from 15 to 0°C. The difference in the sarcoplasmic reticulum's calcium cheleting ability between muscles and species may explain the difference in susceptibility to cold shortening.

Chrystall (1976) reported that by delaying chilling below 8°C until pH 6 is attained, cold shortening can be minimized. Freezing muscle should be delayed until pH 5.7 is reached to avoid thaw shortening (Bendall et al., 1976). Locker and Daines (1976) found muscle temperature during the completion of rigor mortis more important in determining the degree of cold shortening than early pre-rigor temperature history. Bendall (1972) reported cold shortening occurred when muscle was chilled to 10°C before 10 hr postmortem. However, Lochner et al. (1980) felt the "very early postmortem" chilling rate was important in determining beef tenderness. A 2 hr postmortem temperature of 27 to 47°C was found more linearly related to tenderness than the 10-hr temperature.

The effects of cold shortening can be minimized by several means (Chrystall, 1976). The hanging position of the carcass is important in determining the extent of shortening that occurs before skeletal restraints take over. This explains some of the differential shortening of muscles within the carcass (Herring et al., 1965; McCrae et al., 1971). Delaying the chilling of muscles until pH 6 is attained, vacuum aging of muscles or carcass conditioning at ambient temperatures have

been used to lessen cold shortening. High temperature conditioning may hasten rigor development and thus reduce the degree of cold shortening within muscles (Chrystall, 1976). These latter concepts have been used to facilitate hot boning.

Schmidt and Gilbert (1970) hot boned the SM, semitendinosus (ST), longissimus dorsi (LD) and biceps femoris (BF) within 2 hr postmortem and conditioned the vacuum packaged cuts at 15°C for 24 or 48 hr. Cold-boned sides were stored at 9°C until muscle excision at 24 hr postmortem. The 24-hr and 48-hr HB and cold-boned muscles were immediately frozen until taste panel and shear force evaluation. Shear force values for the SM, LD and BF were no different for the control and 24-hr conditioned treatments. However, 48-hr conditioning improved SM tenderness compared with controls and 24-hr conditioning. Increased shear force values were obtained for the hot-boned ST samples conditioned for either 24 or 48 hr when compared with controls. Taste panels found no differences in tenderness, juiciness and overall acceptability for the hot-boned SM, ST and LD conditioned for 24 or 48 hr as compared with controls. General acceptability was improved for the 48-hr conditioned, hot-boned BF as compared with the other treatments. These authors concluded that conditioning at 15°C for 24 hr produced SM and LD muscles as tender as controls, and an additional 24 hr of conditioning produced considerable aging-induced tenderness. However, shear force measured-toughening was observed in pre-rigor excised ST even after conditioning for up to 48 hr.

Chilling (or conditioning) temperatures of -5 to 15°C were used to determine the effects on SM excision at 1 hr postmortem (Follett et al., 1974). After 24 hr of conditioning at 15, 10 or 5°C or 12 hr of chilling

at -5°C, the vacuum-sealed SM muscles were aged at 1°C for 3, 7 or 13 days before Instron tenderness measurements were made. Controls were cold boned at 36 hr postmortem, vacuum packaged and aged at 2 to 3°C. The SM muscles conditioned at temperatures of 15, 10 or 5°C and aged 3, 7 or 13 days were more tender than controls aged the same length of time. The -5°C cooling temperature decreased SM tenderness. No effect on HB tenderness as compared with controls was observed from conditioning at temperatures above 5°C.

Sides from Danish commercial cows were hot-boned at 1 to 1.5 hr after slaughter in a series of trials by Buchter (1977). Muscles and muscle systems [SM, LD, BF, Psoas major (PM), ST, gluteus medius (GM) and quadriceps] from the hindquarter were utilized. The trials involved (1) chilling at 5, 7.5 or 10°C for 24 hr, (2) conditioning at 15°C for 4 hr before chilling at 5, 7.5 or 10°C for 20 hr, (3) conditioning at 15°C for 7 hr before chilling at 5, 7.5 or 10°C for 17 hr or (4) conditioning at 15°C for 7 hr, then chilling at 7.5°C for 17 hr as compared with conditioning at 15°C for 24 hr. Single layer chilling was employed. All vacuum packaged muscles were subsequently aged at 2°C until 10 to 12 days postmortem. Cold-boned cuts were excised at 48 hr postmortem, vacuum packaged and aged at 2°C with HB cuts. Taste panel results for the PM, LD, GM and BF indicate chilling at 5 to 7°C decreased the tenderness of the PM, GM and BF; the LD was not affected. Hot-boned cuts conditioned at 15°C for 7 or 24 hr were scored comparable in taste panel tenderness. Instron shear force measurements averaged for all cuts were higher for HB muscles than cold-boned controls. Decreases in the differences between the two boning treatments were observed with increased

conditioning time at 15°C. Comparisons between conditioning at 15°C for 7 or 24 hr favored the 24-hr treatment, but differences were slight. Hot boning of Danish commercial cows increased toughness of muscles and only by chilling at a very slow rate (15°C for 4 to 7 hr, then 7°C until 24 hr) could this effect be overcome. Buchter (1982) reported that successful (acceptable tenderness) industry-applied hot boning procedures consisted of conditioning 5 hr at 12°C, 17 hr at 7°C and 20 to 24 hr at 2°C after vacuum packaged hindquarter cuts were hot-boned at 1 to 1.5 hr postmortem.

In a study to assess the quality of hot-boned muscles after vacuum aging, Schmidt and Keeman (1974) removed the PM, GM, LD, SM, ST and BF at 1 hr postmortem. Those muscles were stored at 7°C for 4 hr, then at 1°C for 20 hr, then were vacuum packaged at 24 hr postmortem and chilled at 1°C for 7 days. Control sides were aged at 1°C for 8 days before muscle removal. No differences were found in Warner-Bratzler shear force (WBS) values or taste panel traits between the two boning treatments.

Taste panel and instrumental compression tenderness measurements were not significantly affected by HB joints and muscles at 3 hr postmortem (Dransfield et al., 1976). Vacuum packaged hot-boned cuts were conditioned at 10°C for 24 hr, then aged at 1°C for 6 to 10 days. Control sides were chilled at 5°C until 5 hr postmortem, then stored at 1°C until muscle excision at 24 hr postmortem. In general, hot boning increased instrumentally assessed toughness by 10%, a result attributable to random variation between animals, cuts or aging (Dransfield et al., 1976).

Taylor et al. (1980) vacuum packaged 15 primal cuts excised at 1 to 2 hr postmortem and single-layer conditioned the cuts at 10°C for

9 hr and at 1°C for a further 18 hr. Control sides were conditioned for 7 hr at 15°C, and then chilled at 1°C until boned at 48 hr postmortem. Cuts from boning treatments were aged until 5 or 21 days postmortem, when sensory panel scores and instrumental texture values were recorded. No boning treatment differences were found for sensory or texture values, but 21 days aging increased sensory panel texture and juiciness scores and decreased instrumental texture scores.

The triceps brachii (TB) and PM of 46 steer carcasses were either hot boned at 2 hr postmortem or stored at 2 to 4°C until conventionally processed at 48 hr postmortem (Lyon et al., 1983). HB muscles were stored at 2°C until 48 hr after slaughter when muscles from both boning treatments were vacuum packaged, aged at 1 to 5°C until 6 days postmortem, cut into steaks and frozen at -26°C until WBS force values were recorded. For the TB and PM, WBS values were similar to controls. Similarly, Axe et al. (1983) excised the SM and LD at 2 hr postmortem. However, those muscles were processed into steaks at either 24 hr for the HB treatment, or at 48 hr for the conventional treatment. After having been stored at approximately 5°C before processing, steaks were vacuum packaged and aged at 2°C until 6 days postmortem, then frozen until evaluated. Increased taste panel connective tissue amount and WBS values for the hot-boned LD were reported, but no differences for SM taste panel traits and WBS values were found.

Another approach to hot boning has been the conditioning of sides for 2 to 10 hr before muscle excision (Kastner et al., 1973; Falk and Henrickson, 1974; Falk et al., 1975; Kastner and Russell, 1975; Kastner et al., 1976; Will et al., 1976). Kastner et al. (1973) conditioned

sides at 16°C for 2, 5 or 8 hr before hot boning the SM, LD, BF and ST. Hot-boned muscles, stored at 1°C, were cut into steaks at 48 hr postmortem. Control sides were chilled at 2°C for 48 hr before boning. Pooled WBS values for the four muscles were higher for HB steaks conditioned 2 or 5 hr as compared with controls. However, no differences were observed for the 8-hr holding treatment compared with controls. Taste panelists were unable to distinguish differences between controls and any of the hot boning treatments. Kastner et al. (1973) concluded that an acceptable tender product could be successfully hot-boned after 5 to 8 hr of carcass conditioning at 16°C.

Thirty Choice steers were allotted to side conditioning treatments of 3, 5 or 7 hr postmortem at 16°C before hot boning and aging until 48 hr postmortem at 1°C (Falk et al., 1975). Control muscles were removed after a 48-hr chilling period at 1°C. WBS forces were determined for three muscles (SM, LD and ST). Increased WBS values were reported for the 5-hr conditioned hot-boned LD and the 7-hr conditioned hot-boned SM as compared with the LD and SM from the conventionally treated sides. The hot-boned ST was not different from controls regardless of the conditioning period before boning. Hot boning as soon as 3 hr postmortem was deemed feasible. Will et al. (1976) studied the same holding periods (3, 5 or 7 hr) and conditioning temperature (16°C) when assessing the tenderness of hot-boned BF, LD and SM muscles. Three instrumental devices and taste panels were used to assess tenderness. All three muscles for all holding periods were organoleptically similar to controls. When compared to the control, instrumentally measured tenderness was higher (more tender) for the 3-hr hot-boned BF (by WBS), higher for

the 5-hr hot-boned LD (by Nip Tenderometer) and higher for the 7-hr hot-boned SM (by WBS and Nip Tenderometer). Again, 3-hr hot boning was shown feasible for certain muscles.

Conditioning carcasses at 16°C until 6, 8 or 10 hr postmortem was studied by Kastner and Russell (1975) and Kastner et al. (1976). Muscles HB after conditioning and aged at 1°C until 48 hr postmortem, and muscles from cold-boned sides chilled at 1°C until 48 hr postmortem were compared. Shear force means for all muscles SM, ST, BF, LD and supraspinatus (SS) indicated carcasses should be conditioned at 16°C until 8 hr postmortem before muscle excision (Kastner and Russell, 1975; Kastner et al., 1976).

High temperature conditioning (37°C) was studied by Seideman et al. (1983). Muscles (SM, LD and ST) were HB at 2 hr postmortem, vacuum packaged, placed in a 37°C waterbath for 3 hr and finally chilled at 1°C until 48 hr postmortem. Control sides were chilled at 1°C until being boned at 48 hr after slaughter. The hot-boned SM was not different in tenderness from controls. However, decreased LD WBS values and less desirable ST taste panel juiciness, ease of fragmentation, connective tissue amount and overall tenderness scores were reported for hot-boned, conditioned samples. Seideman et al. (1983) reported conditioning at 37°C may have increased proteolysis of myofibrillar proteins resulting in increased LD tenderness, while shortening connective tissue proteins and thus decreasing ST tenderness.

Previously described hot-boning studies have sought to prevent cold-induced toughening and pre-rigor excision effects by delaying the chilling and/or excision time until rigor onset. Electrical

stimulation of carcasses hastens the onset of rigor mortis and, thus, can be used with hot boning to allow earlier cutting and chilling, both of which may be more appealing to meat processors than the previously described hot-boning techniques.

Electrical Stimulation

The use of electrical stimulation (ES) shortly after death to improve the tenderness of muscle is not a new idea. Harsham and Deatherage (1951) patented a beef carcass electrical stimulation process as a means of tenderizing meat. Renewed interest in ES has been spurred by the reported effects on decreasing time between slaughter and grading and the incidence of regrading, increasing muscle tenderness, facilitating hot boning and improving muscle color. Today, ES is used within the meat industry in the U.S., New Zealand, Australia, Great Britain and France even though the primary reasons for using ES may be different from country to country.

When a carcass or side is electrically stimulated, visible massive muscle contraction occurs. Dutson et al. (1980) stated that the major cause of changes that occur with ES is due to muscle energy depletion by the contraction of the muscle. The contractions themselves may also cause some changes. There are several mechanisms by which these changes may alter the tenderness of ES meat.

Postmortem glycolysis rate is accelerated by ES resulting in more rapid lactic acid accumulation and pH decline (De Fremery, 1960; Karpatkin et al., 1964; Forrest and Briskey, 1967; Carse, 1973; Davey et al., 1976; Bendall, 1976; Bendall et al., 1976; Chrystall and Hagyard,

1976; Devine, 1976; Rashid et al., 1983a). Davey et al. (1976) suggested that the rate of glycolysis is accelerated in two phases, first during actual ES and secondly, after stimulation has ceased. The effects during ES are attributed to muscle energy expenditure from contractions. Forrest and Briskey (1967) reported that porcine muscles with a slow rate of glycolysis were more responsive to ES than those with an intermediate rate.

Muscle pH fell at rates two to three times that of normal muscles when lambs were stimulated at 15 min postmortem for 2 min with 250 volts (V) [15 Hertz (Hz); 0.8 amps (A)] pulsed current (Bendall, 1976). ATP levels declined with pH; freezing of lambs was feasible within 3 hr postmortem as compared with 10 hr for controls. In another study, Bendall et al. (1976) investigated the effects of varying voltages, Hz and postmortem stimulation time on the rate of glycolysis in beef. Optimal parameters were reported as 700 V, 25 Hz (3000 pulses) for 2 min at 15 min postmortem. At 1 hr postmortem, pH 6 was reached and 50% of the muscle ATP supply was depleted; pH 5.7 was reached at 1.5 to 2.0 hr postmortem at which time 90% of the ATP supply was depleted. Chrystall and Hagyard (1976) used 300 V and 15 Hz to stimulate lambs for 1 min at 5 min postmortem. Two A were delivered through the carcasses and pH 6 was attained within 1 hr after ES. Pulsed current produced a more rapid pH decline than continuous current (Bowles, 1981). Rashid et al. (1983b) studied the effects of 50 or 350 V and 10,000 or 250 Hz in increasing glycolytic rates of lamb muscles. These researchers concluded that ES with increased voltages and decreased frequencies (Hz) is more effective in increasing glycolytic rates as compared with low voltages and high frequencies.

Because of the rapid fall in pH, carcass aging may start while the muscles are at or near body temperature. Temperature may even rise during ES. Devine (1976) reported a 3°C temperature rise in excised ox sternomandibularis during 2 min of ES. However, Carse (1973) reported a 3°C drop in lamb carcass' temperature during a 30 min ES. The combination of high temperature and low pH has been associated with increased tenderness (Locker and Daines, 1976). Even with rapid chilling, ES sides are warm at rigor onset (Davey et al., 1976). With earlier rapid cooling or freezing of ES products, through-put is increased (Bendall and Rhodes, 1976).

A second and much disputed mechanism of improved tenderness in ES muscle is the prevention of cold shortening or thaw rigor. Bendall et al. (1976), Chrystall and Hagyard (1975) and Davey et al. (1976) have postulated this mechanism. However, measurements of muscle sarcomere lengths have not substantiated this theory. Savell et al. (1977, 1979), Seideman et al. (1979), George et al. (1980), McKeith et al. (1980), Nichols and Cross (1980), Will et al. (1980), Demeyer et al. (1981), Elgasim et al. (1981) and Salm et al. (1981) have reported no sarcomere length differences in muscles from stimulated carcasses, whereas Smith et al. (1977, 1979), Bouton et al. (1980) and George et al. (1980) reported longer sarcomeres in stimulated muscles. Dutson et al. (1980) suggested that under normal chilling conditions, cold shortening reduction is not a major occurrence within ES muscle. In cases of extremely rapid chilling or within certain muscles of the carcass, ES may reduce the toughening effect of cold shortening.

The high temperature, low pH condition existing within ES carcasses may increase proteolysis or hasten its occurrence (Locker and Daines, 1976). Dutson et al. (1980) studied the stability of the lysosomal membrane from stimulated and nonstimulated sheep muscle. A 24 to 30% increase in free activity of lysosomal enzymes that cleave certain myofibrillar protein linkages and possibly connective tissue was reported from ES muscles. Kang et al. (1983) reported the effects of rabbit muscle ES on the postmortem changes of myofibrillar proteins. Minimal changes in actin-myosin interaction during storage of the muscle at 0°C occurred. Furthermore, the enhancement of proteolysis was theorized due to the appearance of the degradative products of troponin-T and myosin heavy chain in stored ES muscle. Savell et al. (1977) found no difference in sarcomere lengths of stimulated goat, lamb and beef muscle, but tenderness increased as compared with controls. These researchers postulated the high temperature, low pH conditions within the ES muscle may have disrupted the lysosomal membrane and released proteolytic enzymes into the muscle tissue. Proteolytic enzymes are more active at higher temperatures and lower pH's. George et al. (1980), Will et al. (1980) and Sorinmade et al. (1982) observed similar increased proteolysis in ES beef muscle. However, Sonaiya et al. (1982) failed to find an effect of ES on the 30,000 dalton component of cow muscle. This high molecular weight component is the degradation product of the calcium activated factor (CAF) protease on troponin-T (Parrish, 1977). Thus, Sonaiya et al. (1982) concluded that ES had no effect on CAF activity.

Micrographs from stimulated and nonstimulated sides have suggested that actual physical disruption of the muscle fibers occurs when carcasses or sides are ES (Savell et al., 1978a; McKeith et al., 1980; Will et al., 1980; Sorinmade et al., 1982). McKeith et al. (1980) reported an increase in contracture bands of muscles of ES cow sides as compared with controls, but no difference was observed for muscle from stimulated steer carcasses as compared to nonstimulated carcasses. Electrically stimulated muscles from steer sides had less defined I-bands and Z-lines within the myofibrillar contraction bands (Savell et al., 1978a). Stretched areas on either side of the sarcomeres involved in the contracture bands were observed. George et al. (1980) found no damage to muscle fibers as a result of electrical stimulation.

The thermal shrinkage temperature of collagen may be affected by ES (Judge et al., 1980). Collagen is of three types, I, II and III; the thermal shrinkage temperature, or degree of intermolecular collagen cross-linking of perimysium, a type III collagen, was lowered by 0.6°C within ES muscle as compared with controls. Hydroxyproline measured collagen content of ES muscle was not different from controls. On the other hand, Rashid et al. (1983a) found no ES effect on the swelling factor of muscles, an indicator of a change in the extent of collagen cross-linkages.

Besides the benefits of increased tenderness (Carse, 1973; Davey et al., 1976; Chrystall and Hagyard, 1976; Dutson et al., 1977; Savell et al., 1977, 1978a, 1978b, 1978c, 1981; Will et al., 1979; George et al., 1980; Judge et al., 1980; Taylor and Marshall, 1980; McKeith et al., 1981a, 1981b; Schroeder et al., 1982; Crouse et al., 1983), electrical

stimulation of carcasses soon after slaughter has other advantages. Savell et al. (1978b, 1978c), McKeith et al. (1980) and Salm et al. (1981) reported more youthful lean, brighter muscle color and less frequent and less severe heat ring. This effect on quality grade parameters could allow for earlier grading (Savell et al., 1978b). Greathouse et al. (1983) failed to find quality grade attribute improvements in stimulated carcasses from implanted and non-implanted young bulls. A softer, coarser textured lean was observed in ES sides than in controls.

Electrical stimulation produced a lighter, brighter red color in displayed beef LD steaks (Sleper et al., 1983). In this study of myoglobin properties of beef LD muscle, total heme concentration and proportions of surface myoglobin, oxymyoglobin and metmyoglobin were not different in the control and ES steak comparisons. The lighter appearance of the ES LD was attributed to more reflected surface and sub-surface light, possibly due to structural changes within the muscle. Under aerobic conditions, stimulated steaks formed more metmyoglobin and had less metmyoglobin reducing ability. Tang and Henrickson (1980) also found LD, SM and ST steaks from stimulated carcasses to be brighter red than control steaks. Oxymyoglobin content was increased with ES, but ES did not affect total pigment and total myoglobin concentrations.

Optimal conditions of ES of beef carcasses soon after slaughter have not been elucidated. Much research has been conducted, but further research is needed. Cross (1979) reviewed the current status of electrical stimulation and proposed research was needed: (1) to determine the mechanisms of tenderizing action associated with ES,

(2) to investigate the proper stimulation parameters (time postmortem, duration and type of current) and (3) to investigate muscle structure response to various types of currents. Electrical control of cell function and the relationship to tissue changes within ES muscle is a research need noted by Asghar and Henrickson (1982). However, the known benefits of electrical stimulation make its use appealing to the meat industry.

Electrical Stimulation and Hot Boning

By combining the economically advantageous process of hot boning with the rigor hastening and tenderizing technique of electrical stimulation, a new concept in meat processing was conceived. Electrical stimulation and hot boning (ESHB) of red meat carcasses produces product of equal or superior quality compared with conventionally processed carcasses. Several systems have been employed.

Beef steers sides were ES at 30 min postmortem and HB at 5 hr postmortem (Gilbert and Davey, 1976). Two min of 3600 V alternating current (AC) was used to deliver 2 A (15 Hz) through the sides. Both control and ES sides were quickly chilled at 4°C; the SM, LD, GM, BF and PM were hot-boned at 5 hr postmortem from ES sides and cold-boned at 24 hr postmortem from controls. Those muscles were halved, wrapped in low gas-permeable plastic bags and either frozen at -18°C or aged at 10°C for 72 hr before freezing. Muscles from ES sides had attained pH 6 within 3 to 4 hr postmortem and had reached ultimate pH before muscle hot boning at 5 hr postmortem. Shear force values indicated that ESHB muscles, immediately frozen, were as tender as aged controls. Immediately frozen control LD samples had a large percentage of samples

in the tough shear force range. Taste panels scored all aged muscles acceptable in tenderness, juiciness and general acceptability. Bacterial quality of the meat was not changed by ESHB. Gilbert and Davey (1976) concluded that fast chilling of carcasses during the delay before HB was advantageous for ESHB beef. Minimal microbial growth and easier hot boning due to greater fat hardening were cited as the rationale for faster chilling; fast chilling had no detrimental tenderness effects.

Gilbert et al. (1977) stimulated beef sides at 60 min postmortem with the same stimulation parameters as Gilbert and Davey (1976) (3600 V, AC, 15 Hz, 2 A through the carcass, 2 min duration). Muscles (SM, LD, GM, BF and PM) were hot-boned and vacuum packaged at approximately 1 hr postmortem. ESHB cuts were either frozen at -35°C at 2 hr postmortem or aged in cartons at 5°C until being frozen at 48 hr postmortem. Controls were cold-boned at 24 hr and either frozen immediately or aged at 10°C for 65 hr before being frozen. Generally, shear force values for unstimulated, unaged muscles were higher than for aged, ESHB muscles. The PM was one exception; no difference was found between the boning treatments when immediate freezing was used. Aging generally decreased unstimulated muscle shear force values (except the LD) as compared with the aged, ESHB muscle. The aged and unaged ESHB SM, GM, and BF had slightly decreased (less acceptable) taste panel scores as compared with control counterpart, but these were not significant. Bacterial growth on the aged ESHB cuts was reduced as compared with aged cold-boned cuts. These authors concluded that immediate freezing or slight aging of ESHB cuts produced beef of superior quality as

compared with conventionally processed cuts. A 2-day chilling cycle was foreseen for product from ESHB carcasses.

Ten Choice grade beef sides were electrically stimulated and ten muscles hot-boned within 1 hr postmortem (Cross et al., 1979). The 3 min stimulation of 250 to 400 V AC (60 Hz) was delivered with 4, 10-sec shocks per min; sides received 1.5 A. Controls were boned after 48-hr storage at 2 to 3°C. Storage properties of both boning treatments were assessed at boning and after boxed aging at 2 to 3°C for 20 days. ESHB cuts had whiter fat, more retained vacuum and less weight loss during storage than controls. Lean color was not affected by boning treatment. The shape of the cold-boned cuts was scored more "acceptable using industry standards" than that of ESHB cuts (Cross et al., 1979).

Vacuum packaged, ESHB beef was also evaluated by Seideman et al. (1979). Palatability, physical and chemical traits of muscle from Good grade steer sides that had been ES at 30 to 40 min postmortem and HB at 50 to 60 min postmortem were evaluated. Sides were stimulated (440 V, AC, 5 A, 50 to 60 Hz) with 25 impulses of 0.5 to 1 sec duration each. Conventionally processed sides were boned after 24-hr storage at 1 to 3°C. After vacuum packaging of the SM and LD muscles from both boning treatments, muscles were stored at 1±1°C for 2 weeks. Taste panels scored the LD from ESHB sides as less juicy when compared with controls; cooking losses were increased and storage losses decreased for the ESHB SM. An increased percentage of 0.03M PO_4^{-3} buffer soluble sarcoplasmic protein from the ESHB LD muscles was reported along with a decrease in the percentage of the myofibrillar, M, C and α actinin proteins. These results were attributed to stimulation induced proteolysis.

Sarcomere lengths, WBS values, taste panel traits and the percentages of other protein components were not different between treatments. A palatable product was produced by stimulating, hot boning and vacuum aging for 2 weeks at 1°C.

Will et al. (1979) delayed-chilled one side from six steer carcasses at 16°C until hot boning at 2 hr postmortem. Sides were stimulated at 30 min postmortem with 15 min of 300 V direct current; the stimulus delivered 1.9 A through the carcass. After HB, the SM, LD, PM, ST and SS were vacuum packaged and stored at 1°C for an additional 48 hr. Corresponding control sides were conditioned at 16°C and boned at 48 hr postmortem. Sarcomere lengths of the ESHB and control muscles were not different. However, the authors reported increased tenderness for ESHB cuts as determined by taste panel scores and WBS values. At 1, 2, 4, 6 and 8 hr postmortem, ATP content was lower for the ESHB SM, LD and SS muscles as compared with control counterparts. By 12 hr, only the ESHB SM and LD had ATP values lower than control counterparts, and by 24 hr, no pH differences between treatments were observed. Will et al. (1979) concluded that ES does speed postmortem glycolysis in muscles, and that ES may have modes of tenderizing action other than the prevention of cold shortening.

At 30 min postmortem, 700 V intermittent AC (60 Hz) was applied to one side of ten Zebu cow carcasses for 2 min (Corte et al., 1980). Muscles (SM, LD and BF) were hot-boned at 45 min after bleeding and either boxed, chilled at 2°C for 5 days and frozen at -20°C, or directly frozen at -40°C. Control cuts boned at 36 to 40 hr post slaughter and chilled at 2°C were treated in a manner similar to ESHB cuts. Taste

panel tenderness ratings for the chilled and aged SM and LD samples from ESHB sides were increased (more tender) as compared with control counterparts; similarly, the immediately frozen ESHB LD tenderness scores were increased relative to the control samples. Shear force values for stimulated, hot-boned LD's of both temperature treatments were more tender than control counterparts. ESHB decreased total side shrink.

Three ES voltage systems (high of 1100 V, low of 110 V and extra low of 45 V) applied at 25 and 45 min postmortem were combined with hot boning at 1 hr (ST and deep pectoral, DP) or 2 hr (SM and TB) postmortem (Bouton et al., 1980). Hot-boned muscles were wrapped in plastic bags and were ice water chilled to induce cold shortening conditions. The 1.25 hr postmortem pH was reduced in all ES treatments except the extra low voltage. Mean pH values were below 6 at 4 hr postmortem for all ESHB voltage treatments. The incidence of cold shortening, as indicated by WBS values, in samples HB at 1 to 2 hr postmortem was reduced with high voltage stimulation. Decreased sarcomere lengths accompanied increased WBS values which led the authors to conclude the ES had prevented cold shortening in the rapidly chilled, HB muscle.

Cross and Tennent (1980) reported the effects of ES sides with 150 to 400 V AC (60 Hz, 1.5 A) for 3 min and boning at 1, 4 or 48 hr postmortem. Choice and Good grade carcasses were utilized. Vacuum packaged muscles were allotted to three storage treatments: (1) frozen at -20°C, (2) chilled for 24 hr at 2 to 3°C and frozen or (3) chilled for 20 days at 2 to 3°C and frozen. WBS and taste panel means indicated that samples from ES carcasses, HB at 1 or 4 hr postmortem, were similar to 48-hr samples from stimulated and nonstimulated

carcasses. Nonstimulated muscles boned at 1, 4 or 48 hr postmortem were not different in tenderness; however, the 1- and 4-hr HB cuts were of borderline tenderness. Nonstimulated muscles, frozen immediately, or after 24 hr of storage, were tougher than ES or non ES cuts stored for 20 days. ES improved the tenderness of 1- and 4-hr HB samples, but they were not equal to ESHB cuts aged 20 days. These authors concluded that minimal negative effects are experienced when ES muscles are hot boned at 1 hr postmortem. However, freezing of ES cuts should be delayed until 24 hr postmortem to avoid tenderness problems.

Kastner et al. (1980) assigned 46 steer carcass sides to two treatments: fabrication after chilling at 2°C for 48 hr, or ES at 1 hr postmortem with 2 min of continuous AC (400 to 600 V, approximately 1.0 A delivered through the carcass, 60 Hz) and HB at 2 hr postmortem. After excision, the SM and LD were vacuum packaged, boxed and stored at 1 to 5°C until 6 days postmortem; then, steaks were cut and frozen. Increased WBS values and decreased taste panel myofibrillar tenderness scores were reported for the ESHB SM muscles as compared with controls. However, differences were slight. LD juiciness scores were increased in the ESHB samples versus control counterparts. Color panel scores for the two treatments were not different after 1 or 4 days of display.

Sides from 80 carcasses were assigned to three hot boning treatments at 1, 2 or 4 hr postmortem (Nichols and Cross, 1980). Sides were ES at 1 hr after slaughter with continuous, 1 A, AC, 60 Hz for 2 min. Voltages ranged from 140 to 200 V, but constant amperage was delivered through the sides. Prior to HB of the SM and LD, sides were stored at 5°C. Control sides (stimulated and nonstimulated) were fabricated at 48 hr postmortem.

Three storage treatments of the vacuum packaged cuts were also compared: muscles immediately frozen at -30°C, muscles stored for 6 hr at 3°C then frozen (-30°C) or muscles chilled at 3°C for 5 days. Postmortem pH decline was affected by ES, boning time and storage treatment, but final sarcomere lengths were unchanged. Appearance of the hot- or cold-boned muscles was not changed by ES, but boning time exerted an influence on the color and color uniformity of the SM muscles. SM muscles excised at 1 or 2 hr postmortem had more desirable and uniform color as compared with 4-hr and 48-hr boning. Severe temperature differentials within the large SM muscle were most likely responsible for the decreased color of the delayed-excised muscles.

Taylor et al. (1980) compared rapidly chilled (-1°C), ESHB muscles excised at 1 to 2 hr postmortem, cuts HB at 1 to 2 hr postmortem and conditioned at 10°C for 9 hr before chilling for 18 hr at 1°C, and control cuts processed at 48 hr. Control sides were conditioned for 7 hr at 15°C, then chilled at 1°C until 48 hr postmortem. Stimulation applied 50 min after slaughter consisted of a 700 V peak current at 25 pulses/sec for 4, 30-sec periods. ESHB vacuum packaged muscles were chilled on trays at -1°C until 24 hr postmortem. All treatments were cartoned after boning and stored at 1°C for 5 or 21 days. Drip losses of the vacuum packaged HB cuts were reduced as compared with controls, but ESHB gave intermediate drip losses. Bacterial contamination of both HB treatments was not increased over cold-boned counterparts. Rapid chilling of the ESHB cuts minimized any tenderizing effect of stimulation; instrumental and sensory panel values of ESHB muscles were not different from the HB or conventionally processed cuts.

Demeyer et al. (1981) used Belgian bulls in their study of ESHB muscle. Sides were stimulated at 45 min postmortem with pulsed, direct current of 50 Hz giving 100 to 150 V applied for about 160 sec. On-rail muscle boning followed ES and was completed within 73 min after ES. Vacuum packaged ESHB subprimals were aged for 7 days at 1°C. Controls were either conditioned at 15°C or chilled at 2°C before muscle excision. Shear force values were decreased for ESHB subprimals as compared with either cold-boned treatment, but sarcomere lengths were unchanged. Tenderizing action from ES other than cold shortening prevention was theorized.

Another European study proposed to investigate the tenderizing action of ES and the product quality obtained from fast chilling of ESHB muscle (Smulders et al., 1981). Ten bulls were stimulated at 5 to 10 min postmortem with 300 V for 1.5 min. Both continuous and intermittent (2.5 sec and 1.5 sec) stimulation was used. Ten bulls served as nonstimulated controls. Hot boning proceeded at 3 to 4 hr after slaughter; vacuum packaged, HB LD samples were ice water chilled for 5 hr and then stored at 2°C. Controls were boned at 24 hr after carcass storage at 2°C. All samples were aged at 2°C until 7 days postmortem. Both continuous and intermittent stimulation increased pH decline for the first 8 hr as compared with controls. Shear force values were lower, but cooking losses were higher for the ESHB-control comparisons. Lighter color was reported for the ESHB LD as compared with controls.

Danish in-plant trials involved electrical stimulation and hot boning of cows and young bulls (Buchter, 1982). One min or 30 to 35

sec of low voltage stimulation was employed immediately after bleeding for cows and young bulls, respectively. Muscles were hot boned "after dressing." For cow carcasses, drip losses were increased 0.2%, but tenderness was unaffected by the ESHB treatment as compared with cold boning. Stimulation increased HB young bull tenderness by 10% as compared with cold boning, and drip losses were not different.

Cuthbertson (1982) reported the results of two factory-based trials which employed on-the-rail hot muscle seaming of ES and non-ES sides. Upon chilling, ESHB cuts reached 7°C in the thickest portions by 24 hr postmortem. Control sides were conditioned at 10°C for 10 hr, then chilled at 0 to 1°C until 48 hr postmortem at which time they were boned. Muscles from all treatments were subsequently vacuum aged at 0 to 1°C until 7 days postmortem. Microbial counts of the ESHB cuts aged until 7 days postmortem increased greatly during the chilling and storage period in the first trial, but greater attention to air circulation around the ESHB cuts during chilling decreased microbial loads of the aged ESHB cuts during the second trial. Shear force values of the ESHB LD from trial 2 were increased, reflective of improved chilling conditions.

Forty-eight sides averaging Good in grade were stimulated at 45 min after slaughter with pulsed (1.6 sec on, .8 sec off) AC for 2 min (Axe et al., 1983). Approximately 1 A of 400 V (60 Hz) current was delivered through the sides. One-half of the ES sides had the SM and LD removed at 2 hr postmortem and chilled in loosely wrapped, oxygen impermeable film at 5°C until 24 hr postmortem steak fabrication and vacuum packaging (ESHB). Muscles from the remaining 23 ES sides were excised and cut

into steaks after 24 hr of 5°C storage (ES). Unstimulated sides were either hot boned at 2 hr postmortem (HB) or remained as controls. Control sides were stored at 5°C until muscle excision and steak cutting at 48 hr postmortem. Storage for all treatments (ESHB, ES, HB and control) were either immediate freezing at -26°C or vacuum aging at 2°C for 6 days before freezing at -26°C. ES did not increase tenderness (WBS and taste panel ratings) of the frozen or aged LD and SM as compared with controls. HB decreased tenderness of the aged and frozen LD, but the aged SM was similar to controls. In both storage treatments for the LD and SM, controls and ESHB samples were not different. Axe et al. (1983) concluded that ES resolved the toughening effects of hot boning.

Three postmortem processing treatments involving HB and ES and two steak storage treatments of PM and TB, long head, were investigated by Lyon et al. (1983). Steers were either stimulated at 1 hr after slaughter and HB at 2 hr postmortem (ESHB), hot boned at 2 hr postmortem (HB) or conventionally processed at 48 hr postmortem. ES parameters applied were 2 min of 400 V, 60 Hz AC (continuous current). Approximately 1 A was delivered through the carcass. Two- and 48-hr boned PM and TB muscles were fabricated into steaks at 48 hr postmortem. Samples from each muscle were then frozen at -26°C or were vacuum packaged and aged in cardboard boxes at 1 to 5°C until 6 days postmortem before being frozen. Increased rates of pH decline were observed in both ESHB muscles as compared with control and HB muscles. Two-hr HB PM and TB steaks, aged for 6 days, had equal or lower WBS values as compared with controls. However, increased (less tender) WBS values

were reported for the unaged TB. Lyon et al. (1983) concluded that ES was not necessary to successfully HB PM and TB muscles, but cautioned that ES may be necessary for other muscles.

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Chapter III

EFFECTS OF ELECTRICAL STIMULATION, HOT BONING AND CHILLING ON BULL SEMIMEMBRANOSUS MUSCLE

ABSTRACT

Taste panel, Warner-Bratzler shear force (WBS) and cooking loss characteristics of the semimembranosus (SM) muscles from thirty electrically stimulated and hot boned (ESHB) or control young bull sides were evaluated. One side from each carcass was electrically stimulated (ES) at 45 min postmortem with 2 min of pulsed (.68 sec on, .32 sec off) alternating current (420 V, 60 Hz). Approximately 1 amp was delivered through the carcass. At 2 hr postmortem the SM was excised from each ES side, loosely wrapped in oxygen impermeable film and chilled in a tray (ESHB-tray) or in a cardboard box (ESHB-box). The SM from each control side was removed at 48 hr postmortem. All control carcasses and ESHB muscles were chilled initially at 5 to 7°C until 24 hr postmortem, and then stored at 2 to 4°C for an additional 24 hr. At 48 hr postmortem, WBS and taste panel steaks were cut, vacuum packaged, aged (2 to 4°C) until 6 days postmortem and then were frozen at -20°C until evaluated. Taste panel beef flavor was scored as more intense ($P<.05$) for the control steaks than for steaks from either of the ESHB treatments. No other differences between treatments were found ($P>.05$) for WBS, cooking losses or taste panel traits.

INTRODUCTION

The use of young bulls for block beef production is gaining increased attention because bulls have more rapid and more efficient gains and leaner carcasses than steers or heifers. However, research has shown bull meat to be more variable in palatability (particularly tenderness) than steers or heifers of the same chronological age (Seideman et al., 1982). Hot boning too has received much attention because of the potential economic benefits of that process (Cuthbertson, 1979; Erickson et al., 1980).

Storage of hot boned (HB) muscle at approximately 5°C followed by aging at conventional refrigeration temperatures has produced steaks equal in tenderness to control comparisons (Follett et al., 1974; Lyon et al., 1983). However, Buchter (1977), using comparable storage conditions and aging practices, found the HB product to be less tender than control counterparts. But, when electrical stimulation (ES) was coupled with similar storage and aging conditions, HB muscles were equal or superior to control counterparts (Axe et al., 1983). Even though several ESHB systems have been successful (Kastner, 1982), electrical stimulation and hot boning should be further evaluated. This is particularly true for young bull beef as the spectrum of ESHB systems needs to be evaluated in light of present and future production practices. Additionally, ES may not only aid HB, but may also reduce the variability in tenderness experienced with bull beef (Riley et al., 1983). Even though ESHB studies involving bulls have produced a product that was equal (Smulders et al., 1981) or superior (Buchter, 1982) to

control comparisons, these involved ES, HB and storage and aging procedures different than those of this study.

Thus, our objective was to evaluate the effects of electrical stimulation, hot boning and chilling on the palatability and cooking loss characteristics of young bull semimembranosus muscle.

EXPERIMENTAL METHODS

Thirty Angus bulls were allotted to three groups of ten bulls each. At 320 days of age, bulls were placed in dry lot pens and fed a 75% concentrate ration. Animals in group 1 were implanted with Ralgro® (a protein anabolic metabolite from Gibberella zeae) at birth and at 106 day intervals until slaughter. Animals in groups 2 and 3 were not implanted (Greathouse et al., 1983). Table 1 contains carcass characteristics of the three groups.

Table 1 - Means for carcass characteristics for bulls.

Group	Live weight, kg	Hot carcass weight, kg	USDA quality grade[a]	Adjusted fat thickness, cm	Avg. age days
1	501	309	Good-87	1.57	522
2	515	326	Good-76	1.32	552
3	454	279	Good-75	1.02	581

[a]Grade superscript, 67-100 = High Good.

Normal slaughter procedures were followed. At 45 min postmortem, one side of each carcass was electrically stimulated for 2 min with 420 volts (V) of pulsed (.68 sec on, .32 sec off) alternating current (60 Hertz, Hz). Approximately 1 amp was delivered through the carcass. Stimulation was accomplished by inserting one stainless steel probe laterally along the humerus and one in the posterior end of the

semimembranosus (SM) muscle. ES was randomly assigned between sides of each carcass. AT 2 hr postmortem, the SM muscle was hot boned (HB) from the ES side (ESHB), loosely wrapped in oxygen impermeable film and chilled at 5 to 7°C in a cardboard box (ESHB-box) or in a tray (ESHB-tray) at 5 to 7°C. ESHB box and tray treatments were randomized within each group.

Control sides were chilled at 5 to 7°C until 24 hr postmortem and then stored at 2 to 4°C until 48 hr postmortem. At that time, those sides were ribbed, carcass data were collected, and the SM muscles were excised.

Temperature and pH decline data were collected at 45 min (pH only), 2, 4, 6, 8 and 24 hr postmortem for all treatments. Thermometers were inserted in the approximate center of the SM muscle, 20 cm above the pubic symphysis; cores (1.27 cm diameter) for pH determinations were removed from an area 2.5 cm posterior to the pubic symphysis. A 1 to 2 g sample was blended with 10 ml of 5 mM NaIAc in 150 mM KCl (Bendall, 1973) and the pH determined.

Steaks for taste panel and Warner-Bratzler shear force analyses were cut from ESHB-box, ESHB-tray and control SM muscles at 48 hr postmortem. Two adjacent 2.54 cm steaks were removed from the proximal end of each SM muscle. Steaks were vacuum packaged in oxygen impermeable film and aged in a cardboard box at 2 to 4°C until 6 days postmortem. After aging, steaks were frozen and stored at -20°C until evaluated.

After not more than 7 months of frozen storage, four pairs of steaks from the ESHB and control treatments (eight steaks total) were randomly selected for taste panel evaluation. Steaks were thawed overnight at 2°C and modified oven broiled at 163°C to an internal

temperature of 70°C. All cooking temperatures were measured with a thermocouple attached to a potentiometer. Taste panel cores were removed perpendicular to the meat surface using the drill press method of Kastner and Henrickson (1969). The 1.27 cm diameter cores were kept warm in egg poaching pans which were warmed with hot water.

A six-member taste panel was selected, trained and served in accordance with AMSA Guidelines for Cookery and Sensory Evaluation of Meat (AMSA, 1978). Panelists scored the SM cores for juiciness, flavor intensity, myofibrillar tenderness, overall tenderness and connective tissue amount, using an 8-point scale for each trait (8 = extremely juicy, extremely intense flavor, extremely tender or no connective tissue; 1 = extremely dry, extremely bland flavor, extremely tough or abundant connective tissue). Serving orders were randomized and no more than two sessions were held per day.

Steaks for Warner-Bratzler shear force evaluation also were analyzed for total cooking losses. Thawing and cooking procedures and sample testing order were the same as for the taste panel steaks. However, before cooking, all subcutaneous fat was removed from the steaks; steaks were lightly blotted, weighed, cooked, lightly blotted and reweighed. Raw and cooked weight differences were used to calculate total cooking losses. After cooling for 2 hr to 21°C, eight 1.27 cm diameter cores were removed in the same manner as for taste panel samples. Cores were sheared once with a Warner-Bratzler shear device and the average peak shear force was calculated.

Statistical Analysis

Analysis of variance was used to test for differences; groups 1, 2 and 3 were pooled. Where differences ($P<.05$) existed among the treatments, means were separated using the least significant difference procedure (Barr et al., 1982).

RESULTS AND DISCUSSION

Taste Panel, Warner-Bratzler Shear Force and Cooking Loss

Means for taste panel, Warner-Bratzler shear force (WBS) and cooking loss values from ESHB-tray, ESHB-box and control side treatments are presented in Table 2. Beef flavor was scored as more intense ($P<.05$) for control steaks than for steaks from either ESHB treatment. No differences were found for other taste panel traits and WBS values ($P>.05$).

Our results agree with Axe et al. (1983) who stimulated steer sides and then hot boned, stored and aged steaks for times and at temperatures similar to those used in this study. Our procedures were different from those authors in that the pulse rate during stimulation was different and subprimals, not steaks, were aged. Our ESHB technique improved upon the technique of Kastner et al. (1980) who evaluated SM muscles from steer sides that were ES (continuous, not pulsed) at 1 hr, HB at 2 hr postmortem and aged at 1 to 5°C until 6 days postmortem. Even though our treatments were different from those of Buchter (1982) and Smulders et al. (1981), our results agree with those authors in that the ESHB systems may be successfully applied to bull carcasses.

Contrary to our results, some researchers have reported that ES increased taste panel beef flavor intensity as compared with unstimulated carcasses (Davey et al., 1976; Savell et al., 1978; Greathouse et al., 1983). Elgasim et al. (1981) and McKeith et al. (1981) found beef flavor unaffected by ES and Corte et al. (1980), Kastner et al. (1980) and Axe et al. (1983) reported beef flavor unaffected by ESHB.

Table 2 - Taste panel[a], Warner-Bratzler shear force and cooking loss means by treatments for the semimembranosus muscle.

Variable	Control	ESHB-tray[b]	ESHB-box[c]	Std. dev. of means
Flavor intensity	6.1[d]	5.9[e]	6.0[e]	± 0.05
Juiciness	5.5	5.3	5.3	± 0.12
Connective tissue amount	5.4	5.4	5.5	± 0.10
Myofibrillar tenderness	5.7	5.7	5.7	± 0.11
Overall tenderness	5.5	5.5	5.5	± 0.11
Warner-Bratzler shear force (kg)	3.8	3.7	3.7	± 0.33
Cooking loss (%)	27.4	25.0	27.2	± 1.20

[a]Scores: 7 = very intense, very juicy, practically none or very tender;

6 = moderately intense, moderately juicy, traces, or moderately tender;

5 = slightly intense, slightly juicy, slight or slightly tender.

[b]Muscle chilled in a tray.

[c]Muscle chilled in a box.

[de]Means within same row with different superscripts differ ($P<.05$).

Cooking losses for the ESHB-tray, ESHB-box and control steaks were not different (P>.05, Table 2). These results disagree with Axe et al. (1983) who found decreased cooking losses for SM samples from ESHB steers when compared with control counterparts.

pH and Temperature Declines

Side ES at 45 min postmortem effectively increased the pH decline in both ESHB treatments as compared with the control treatment (Fig. 1). By the time the SM was hot boned at 2 hr postmortem, the mean pH had attained 6.0. Controls reached pH 6 by 4 hr postmortem. Susceptibility to cold shortening is reduced after a pH of 6 is attained (Chrystall, 1976). Thus, cold shortening should not have been a problem in either ESHB treatment or the controls. When temperature declines (Fig. 2) are examined, both ESHB treatments were approximately 38°C at 2 hr postmortem. Bendall (1972) reported carcasses should not be chilled to 10°C before 10 hr to avoid cold-induced toughening. At 10 hr postmortem, temperatures for all treatments were well above 10°C, further evidence that cold shortening conditions did not exist for any of the treatments.

Figure 1 also illustrates that between 2 and 10 hr postmortem, ESHB-box muscles had a slightly increased pH decline as compared with ESHB-tray treatment. This agrees with the findings of Rashid et al. (1983) who found pH declines in ES ovine muscle to be increased by slowing the chilling rate. However, differences in their pH declines between the two ES treatments were of a greater magnitude than in our study. Rashid et al. (1983) slowly chilled sides at 14°C for 5 hr,

Figure 1 - Postmortem pH decline for the semimembranosus muscle by treatments.

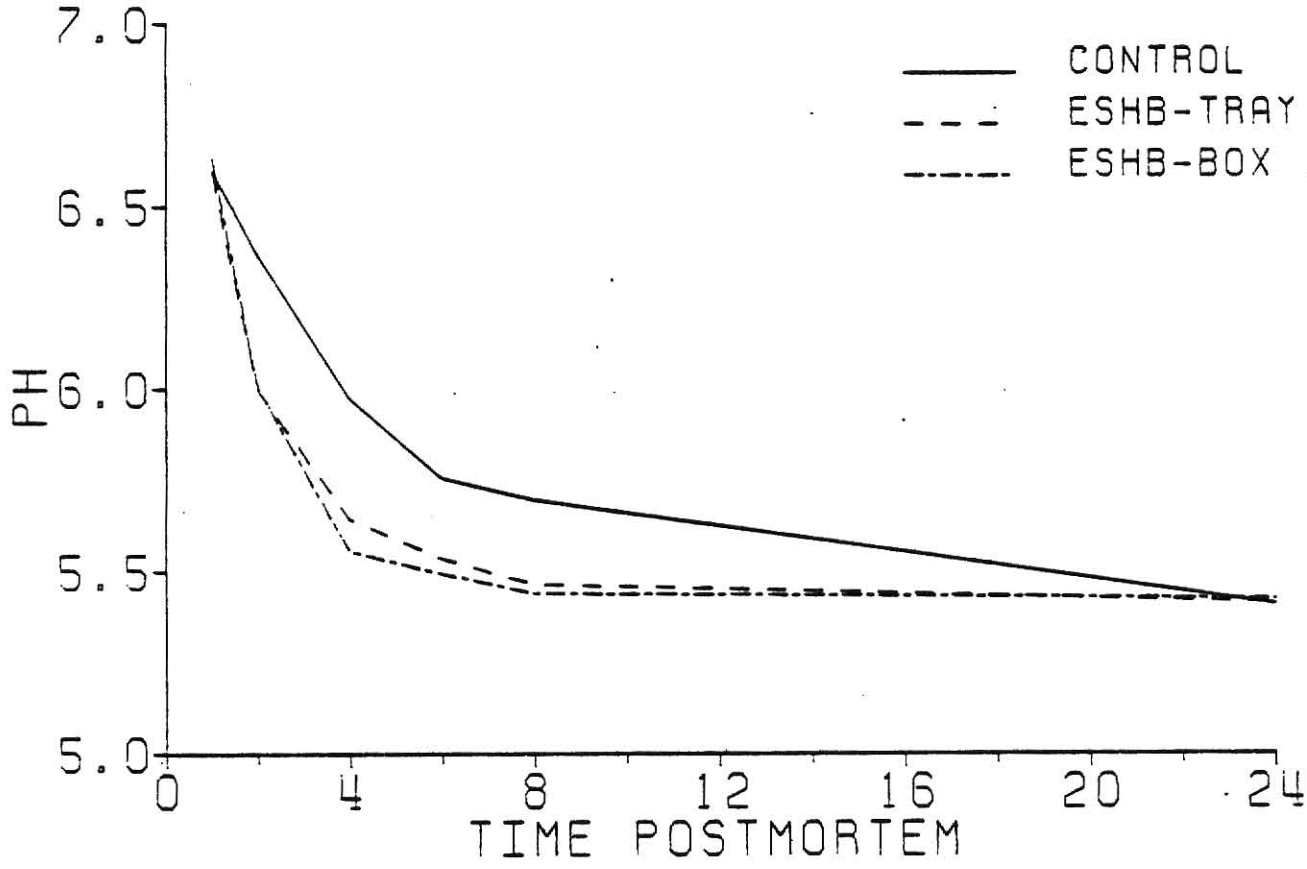
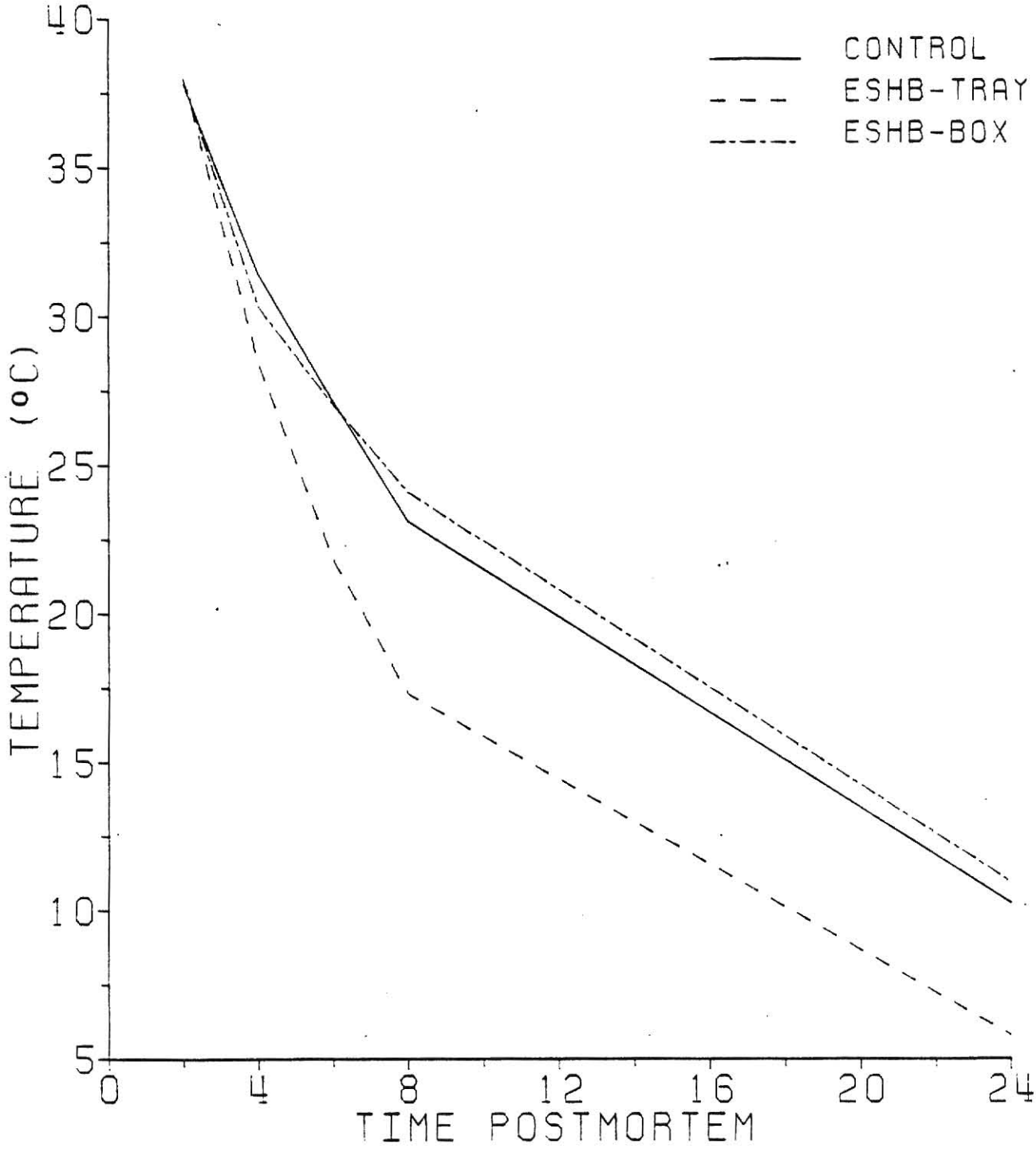

7.0
6.5
6.0
5.5
5.0
PH
0
4
8
12
16
20
24
TIME POSTMORTEM
CONTROL
ESHB-TRAY
ESHB-BOX

Figure 2 - Postmortem temperature decline for the semimembranosus muscle by treatments.


CONTROL
ESHB-TRAY
ESHB-BOX
TEMPERATURE (°C)
40
35
30
25
20
15
10
5
0
4
8
12
16
20
24
TIME POSTMORTEM

while faster chilling was accomplished at 2°C. No difference in pH declines for fast and slow chilling treatments was reported for non-ES muscle (Bendall, 1972); however, a study by Marsh (1954) showed that chilling rate affects the relative rate of pH decline in non-ES muscle.

Fung et al. (1981) studied the effect of initial chilling rate on the microbial quality of hot-boned beef. These researchers reported that chilling HB muscle to 21°C within 9 hr of boning increased bacterial quality, color and odor scores as compared with slower chilling rates. Muscle chilled using the ESHB-tray treatment reached 21°C within 4 hr of boning (6 hr postmortem), but muscle chilled more slowly (ESHB-box) did not attain this temperature until approximately 10 hr after boning (12 hr postmortem, Fig. 2). The ESHB-tray treatment would likely produce SM muscle of higher microbial quality as compared with the ESHB-box treatment without affecting the palatability of the product.

SUMMARY

Young bull SM tenderness and cooking loss characteristics were not adversely affected by side ES at 45 min postmortem and HB at 2 hr postmortem or by chilling the muscle in trays or boxes at 5 to 7°C ambient temperatures for the first 24 hr then 2 to 4°C for a further 5 days when compared with conventional processing. Chilling conditions similar to those of tray-stored cuts would likely be the most compatible with acceptable microbial quality (Fung et al., 1981). ES accelerated postmortem glycolysis in the HB muscle, resulting in relatively low pH values at high temperatures, and thus reduced the possibility of cold-induced and pre-rigor excision toughening observed in some HB systems (Kastner, 1982).

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Chapter IV

APPENDIX

Table 3 - Degrees of freedom, mean square error terms and F-values for taste panel traits, Warner-Bratzler shear force and cooking loss percentage means for the semimembranosus muscle.

Source of Variation	D.F.	M.S.	F
Flavor Intensity	57	0.0707	2.84*
Juiciness	57	0.4462	0.45
Connective Tissue Amount	57	0.2964	0.19
Myofibrillar Tenderness	57	0.3937	0.03
Overall Tenderness	57	0.3671	0.08
Warner-Bratzler Shear Force	57	3.2051	0.12
Cooking Loss	57	43.1152	0.73

*$P<.05$.

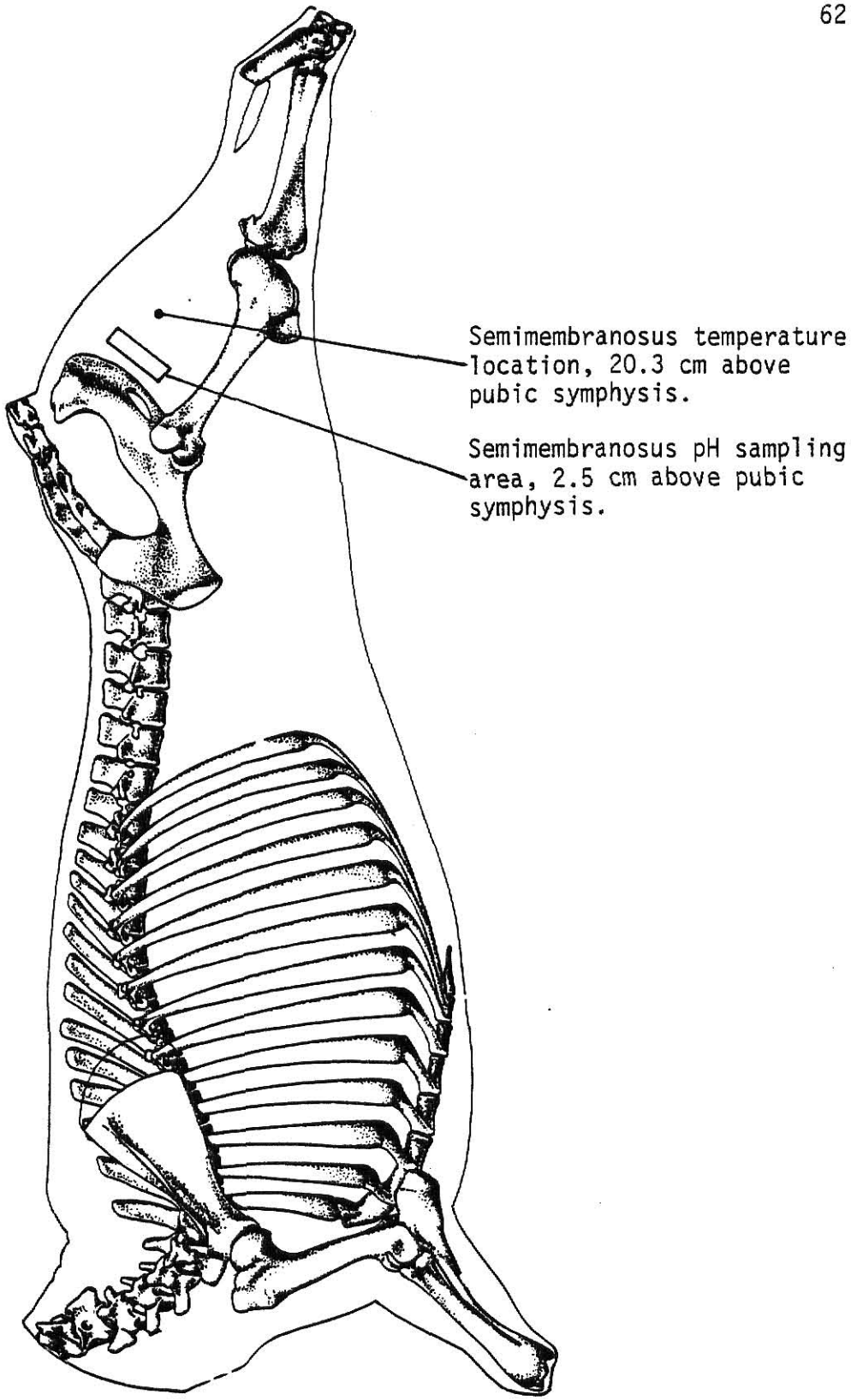
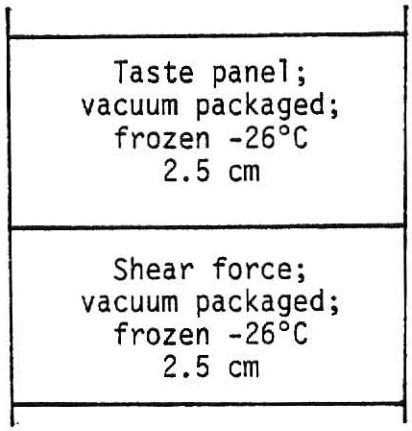


Figure 3 - Temperature and pH sampling locations.

Proximal End of Semimembranosus



Distal End of Semimembranosus

Figure 4 - Sampling arrangement for the semimembranosus muscle.

ILLEGIBLE DOCUMENT

THE FOLLOWING DOCUMENT(S) IS OF POOR LEGIBILITY IN THE ORIGINAL

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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 5 - Taste panel evaluation sheet for beef palatability.

EFFECTS OF ELECTRICAL STIMULATION, HOT BONING AND CHILLING ON BULL SEMIMEMBRANOSUS MUSCLE

by

SUSAN DUDLEY SHIVAS

B.S., University of Tennessee, 1978

AN ABSTRACT OF A MASTER'S THESIS

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Taste panel, Warner-Bratzler shear force (WBS) and cooking loss characteristics of the semimembranosus (SM) muscles from thirty electrically stimulated and hot boned (ESHB) or control young bull sides were evaluated. One side from each carcass was electrically stimulated (ES) at 45 min postmortem with 2 min of pulsed (.68 sec on, .32 sec off) alternating current (420 V, 60 Hz). Approximately 1 amp was delivered through the carcass. At 2 hr postmortem the SM was excised from each ES side, loosely wrapped in oxygen impermeable film and chilled in a tray (ESHB-tray) or in a cardboard box (ESHB-box). The SM from each control side was removed at 48 hr postmortem. All control carcasses and ESHB muscles were chilled initially at 5 to 7°C until 24 hr postmortem, and then stored at 2 to 4°C for an additional 24 hr. At 48 hr postmortem, WBS and taste panel steaks were cut, vacuum packaged, aged (2 to 4°C) until 6 days postmortem and then were frozen at -20°C until evaluated. Taste panel beef flavor was scored as more intense ($P<.05$) for the control steaks than for steaks from either of the ESHB treatments. No other differences between treatments were found ($P>.05$) for WBS, cooking losses or taste panel traits.