BEEF CARCASS ELECTRICAL STIMULATION AND HOT BONING EFFECTS ON PSOAS MAJOR AND TRICEPS BRACHII MUSCLES

by

MARY LYON

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Chapter I

GENERAL INTRODUCTION

Hot boning or hot processing as a method of beef carcass fabrication is an economically attractive technique (Kastner, 1977; Cuthbertson, 1979; Kansas State University, 1980). Due to tenderness problems associated with excision, chilling and freezing of pre-rigor muscle, careful attention must be given to hot-processing techniques to ensure quality steak and roast items. The following approaches have resulted in a hot-boned product of equal or superior quality to that conventionally processed: carcasses have been cut within 1 to 2 hr postmortem with muscles being aged 24 to 48 hr at 15°C or 8 days at 1°C before evaluation (Schmidt and Gilbert, 1970; Schmidt and Keman, 1974); carcasses have been conditioned at 15 to 16°C for 3 to 10 hr before boning (Kastner et al., 1973; Falk et al., 1975; Kastner and Russell, 1975; Kastner et al., 1976); or combinations of these approaches have been used (Dransfield et al., 1976).

Electrical stimulation of beef carcasses soon after slaughter accelerates postmortem glycolysis and the onset of rigor mortis (Carse, 1973; Deatherage, 1980). Several workers have investigated electrical stimulation and its effect on postmortem muscle (Cross, 1979a). The various electrical stimulation parameters which have been utilized have generally resulted in increased longissimus dorsi muscle

tenderness (Dutson et al., 1980), but results from other muscles have been variable.

The increased rate of rigor mortis onset initiated by electrical stimulation may be beneficial to the hot-boning process, allowing early boning of carcasses without experiencing tenderness problems often associated with pre-rigor muscle excision and treatment (Gilbert and Davey, 1976; Gilbert et al., 1977).

Mechanical tenderization is a technique used extensively in Hotel, Restaurant and Institutional meat trade to ensure tenderness of cuts and to upgrade some muscles (Miller, 1975); therefore, this technique may be effectively used in conjunction with hot boning.

The following review of literature summarizes previous research relating to hot boning, electrical stimulation and blade tenderization. Chapter III details our study which investigates optimal systems of electrical stimulation and hot boning of beef carcasses.

Chapter II

GENERAL REVIEW OF LITERATURE

Hot Boning

Hot boning (HB) or hot processing is the fabrication of carcasses soon after slaughter and before conventional chilling. HB is an attractive technique due to attributed economic advantages.

Potential advantages of HB have been studied by several workers. Henrickson (1975) reported that when the space required to chill the edible portion of a 600 lb. Choice beef carcass was compared with space necessary to conventionally chill the intact carcass, the refrigerated space requirement for cooling the edible portion was at least 80% less than space conventionally used. A 50% space reduction was reported by Dvorak (1980). Total savings in energy for refrigeration could be 50% or more (Henrickson, 1975). Dvorak (1980) reported that because bone and unwanted trim were excluded from refrigerated spaces, there was an inplant saving of about 30% in direct refrigeration cost of chilling. Because chilling time was reduced by 24 hr, overall refrigeration energy savings of 50% or more were projected (Dvorak, 1980). Kansas State University (1980) reported major energy savings from omitting the shroud load and from not cooling bones and fat trim. Additional energy savings came from external building transmission, electrical equipment load and lighting

loads. At 1979 electric rates, total energy savings amounted to as much as 34 cents per carcass.

Reduction in labor and material are also major potential advantages of HB. HB on the rail required 35-40% less labor than cold boning (CB) on the table. Neck pinning, scribbing and shrouding of HB carcasses and functions needed to support those operations would not be necessary (Cross, 1979b). Shrinkage of HB vacuum packaged beef was 2% less than conventionally processed beef (USDA, undated). Dvorak (1980) reported in plant resident time for HB beef could be reduced by 24 hr. Therefore, significant savings in energy, yield, materials and supplies, labor and interest on fixed capital and inventory may be attributed to HB. Kansas State University (1980) reported combined savings including energy, materials and supplies, labor, interest on fixed capital and interest on inventory of up to $2.75 per carcass (1979 prices).

There are potential disadvantages that must be considered when considering HB. Presently there is no system for quality or yield grading of hot beef carcasses. Retaining identity and shape of cuts are problems which can be overcome, but procedural modifications are necessary (Dvorak, 1980). Microbial problems may occur if HB beef is not properly chilled (Fung et al., 1980; Kotula, 1980). Also precautions must be considered in HB because of tenderness problems associated with cutting, chilling, and freezing of pre-rigor muscle. Beef muscle excised and chilled or frozen prior to the onset of rigor mortis can be significantly less tender because of pre-rigor excision, cold shortening and thaw rigor effects (Locker and Hagyard, 1963;

Marsh et al., 1968; Marsh, 1966, 1972; Davey and Gilbert, 1974). Therefore, careful processing techniques must be utilized to insure high quality steak and roast items. The following approaches have been studied: 1) carcasses have been cut within 1 to 2 hr postmortem with muscles being aged 24 to 48 hr at 15°C or 8 days at 1°C before evaluation; 2) carcasses have been held at 15 to 16°C 3 to 10 hr before boning; and 3) combinations of those two methods have been used.

Schmidt and Gilbert (1970) compared the tenderness of beef muscles removed 2 hr postmortem and stored at 15°C for 24 or 48 hr with the corresponding muscles left on the carcass and chilled at 9°C for 24 hr then excised. The biceps femoris (BF) and longissimus dorsi (LD) muscles HB and stored at 15°C for 24 hr were of equivalent tenderness to their controls while those HB and stored at 15°C for 48 hr were significantly more tender than controls. The semimembranosus (SM) showed no treatment effect while the HB semitendinosus (ST) muscles were significantly tougher than their controls.

In 1974, Schmidt and Keman HB one side of six carcasses 1 hr postmortem, stored the muscles at 7°C for 4 hr and then chilled them at 1°C until 24 hr postmortem, at which time they were vacuum packaged and placed at 1°C for 7 days. The opposite sides were CB after being stored 8 days postmortem at 1°C. Shear force values (SFV) for HB and CB steaks (LD, psoas major (PM), and gluteus medius (GM)) and roasts (ST, SM, BF and quadriceps femoris (QF)) were not statistically different.

Follett et al. (1974) excised the SM muscle from 24 beef sides at 1 hr postmortem, chilled them at -5°C until 12 hr postmortem, or

at 5, 10 or 15°C until 24 hr postmortem and subsequently stored them at 0°C for up to 12 days. These were compared with corresponding muscles chilled in intact sides at 2 to 3°C before being excised at 36 hr postmortem and then stored with the HB counterparts at 0°C. With the exception of the group chilled at -5°C, the HB muscles had lower SFV at 3 to 13 days postmortem than CB muscles.

Kastner et al. (1973) compared muscles from sides HB after being conditioned until 2, 5 or 8 hr postmortem at 16°C with corresponding muscles from sides chilled until 48 hr postmortem at 2°C before muscle excision. Steaks from intact sides conditioned until 8 hr postmortem had equal or smaller SFV when compared with control sides.

Falk et al. (1975) and Will et al. (1976) assigned sides to one of two treatments: 1) muscles were HB after conditioning at 16°C until 3, 5 or 7 hr postmortem; or 2) muscles were excised after a 48 hr chilling period at 1°C. SFV differences between HB and CB LD, ST and SM muscles excised 3 hr postmortem were not considered of practical importance (Falk et al., 1975). No major differences were found between BF, LD or SM muscles fabricated 48 hr postmortem and those from carcasses conditioned 3, 5 or 7 hr postmortem at 16°C (Will et al., 1976).

Kastner and Russell (1975) and Kastner et al. (1976) compared muscles from sides conditioned at 16°C for 6, 8 or 10 hr postmortem before fabrication with muscles from corresponding sides chilled at 2°C for 48 hr. Kastner et al. (1976) reported that the LD could be successfully HB at 6 hr postmortem without affecting acceptability of tenderness, although holding 8 hr postmortem was recommended to

help insure a tender product. Kastner and Russell (1975) reported different ($P < .05$) SFV for the ST and supraspinatus (SS) HB after the 6 hr holding period versus their CB counterparts, with HB muscles having larger SFV. At 8 hr the HB ST and BF muscles had higher ($P < .10$) SFV than the CB samples; however, the reverse was true for the LD. At 10 hr there were no differences ($P > .10$) between treatments for any muscle.

Dransfield et al. (1976) reported that the eating quality of muscle excised within 3 hr postmortem and conditioned at 10°C until 24 hr postmortem was equal to that of controls stored at ambient temperature for 5 hr then chilled at 1°C. Muscles were also aged at 1°C for 6-10 days. These authors reported that aging enhanced the tenderness of HB beef.

Electrical Stimulation

Introduction

Tenderness is generally regarded as the most important palatability characteristic of meat (Chrystall, 1976). Until 1959, the connective tissue component attracted the most attention as the cause of variation in the tenderness of muscle (Locker, 1976). Since 1960, the state of contraction of muscle fibers following rigor mortis has demanded the most intensive study. The discovery that muscle shortening is a major cause of meat toughness has led to the realization that postmortem treatments far outweigh live animal factors such as breed, age and preslaughter state in determining eating quality (Davey, 1969; Locker

et al., 1975). Locker and Hagyard (1963) demonstrated that early post-mortem exposure of lamb carcasses to cold induces muscle shortening termed "cold shortening." This phenomenon occurs when pre-rigor muscle is chilled to temperatures below about 8°C (Chrystall, 1976). The rate and extent of cold shortening is dependent on the degree of rigor onset at the time of cooling (Marsh and Leet, 1966). Cold shortening is of great practical importance, for it causes very severe toughening. Marsh et al. (1968) showed that rapid freezing and thawing can also induce shortening (thaw shortening or thaw rigor). Lamb is particularly vulnerable because of its small size and subsequent rapid cooling, but the effect is also responsible for appreciable toughening in beef. Bendall and Rhodes (1976) reported that rapid cooling of beef muscles to 2°C can be started without danger of cold shortening as soon as pH 6.0 is reached. At that time about 50% of the ATP has disappeared (Bendall et al., 1976). Rapid freezing without danger of thaw rigor may be initiated as soon as pH 5.7 is reached (Bendall and Rhodes, 1976) when 90% of the ATP has disappeared (Bendall et al., 1976).

Different approaches have been investigated to restrict, minimize or prevent cold shortening by carcass suspension (Herring et al., 1965; Hostetler et al., 1970; Davey and Gilbert, 1975) and high temperature conditioning (Smith et al., 1971; Dutson et al., 1975; Fields et al., 1976). Although these procedures have been shown to improve tenderness, there are production time problems with the use of high temperature conditioning and changes in carcass shape with the use of non-conventional carcass suspension which have deterred industry application of either method.

An alternative for increasing tenderness and/or preventing cold shortening is the electrical stimulation (ES) of the carcass shortly following slaughter. The concept of ES to improve tenderness is not new; its use for that purpose was first suggested by Benjamin Franklin in 1749 (Lopez and Herbert, 1975). Franklin reported that "killing turkeys electrically, with the pleasant side effect that it made them uncommonly tender, was the first practical application that had been found for electricity." Harsham and Deatherage (1951) patented (US Patent 2544681) a process for ES of beef carcasses. New Zealand workers (Carse, 1973; Chrystall and Hagyard, 1975) developed an ES protocol to prevent toughening of lamb carcasses when chilled or frozen soon postmortem. The method is now applied commercially in New Zealand for accelerated conditioning of lamb. Workers in New Zealand, United States, Great Britain, Australia and Canada have reported further ES studies involving lamb, beef and goats (Bendall, 1976; Bendall and Rhodes, 1976; McCollum and Henrickson, 1977; Smith et al., 1977; Bouton et al., 1980a; Smith et al., 1980).

ES of postmortem muscle is known to accelerate glycolysis (Cori, 1945; Karpatkin et al., 1964). Carse (1973) reported that ES of lamb carcasses increased subsequent rates of postmortem glycolysis and thus hastened rigor onset. Numerous combinations of ES parameters have been investigated and all generally speed rigor onset. Early researchers have generally agreed that ES minimizes muscle toughening due to cold shortening (Carse, 1973; Chrystall and Hagyard, 1975; Davey et al., 1976). Later research indicated other mechanisms may also act in tenderness improvement, such as lysosomal enzyme activity, physical

disruption of tissue, and decreased connective tissue thermal shrinkage stability (Dutson et al., 1977; Savell et al., 1977a; Bowling et al., 1978; Dutson et al., 1980; George et al., 1980; Judge et al., 1980).

Effect on Postmortem pH Decline

Carse (1973) ES lamb carcasses 30-40 min postmortem for 30 min with square wave pulses (2-13.5 msec duration) at 0-250 Volts (V) delivered at rates from 3-17.5 per sec. Within the ranges of duration, voltage, and frequency used, only voltage appeared to affect the rate of glycolysis, with higher voltages increasing the rate of glycolysis. In a second experiment, Carse (1973) utilized pulses of 12 msec duration at 250 V applied at a rate of 3 per sec and reported that increasing the pulse voltage reduced the time required for muscle to reach pH 6.0. In carcasses conditioned at 18°C until 5 hr postmortem, then stored at -18°C, unstimulated LD, SM, BF and GM muscles reached pH 6.0 in 15.4 hr, compared with 3.0 hr for ES counterparts.

Chrystall and Hagyard (1976) examined the practicality of using high voltages (3600 V) to accelerate glycolysis in lamb. Within 5 min of slaughter, lamb carcasses (fleece on) were ES for 55 sec with sinusoidal pulses (5 msec duration, 15 Hertz (Hz), 3600 V), the polarity changing with successive pulses. The load current fell to approximately 1600 V, giving a carcass current of 2 amperes (A). Glycolysis was monitored through measurement of the pH of LD muscles for 24 hr on carcasses conditioned at 15°C. ES caused a marked acceleration of glycolysis compared with muscles from unstimulated carcasses, with ES and unstimulated muscles reaching pH 6.0 in 1 hr

and 14 hr, respectively. The ultimate pH in both ES and unstimulated carcasses was about 5.5.

Bendall (1976) studied the effects of voltage and investigated the biochemical changes, particularly the exhaustion of ATP, in lamb muscle. Undressed lamb carcasses were ES within 15 min post slaughter with 250 V from an alternating current (AC) source adapted to give sinusoidal pulses at rates between 1 and 20 Hz; the pulse width and gap between pulses were equal at each frequency. The current flowing through the carcasses at 15 Hz was about 0.8 A. Carcasses were ES for 1.5 min with the total number of pulses varied between 600 and 1350, but the authors reported no detectable differences over this range in the rate and extent of pH fall of the musculature. ES caused an immediate rapid pH fall of 0.42 ± 0.04 units in the LD, followed by an increased rate of fall over the subsequent 2 hr period. At an ambient temperature of 19-20°C, ES muscle reached pH 6.0 in 2 hr compared with 7 hr for unstimulated muscle. The time taken to reduce the ATP level by half was 1.6 hr in the ES muscles, but more than 4 hr in the unstimulated controls. In the BF muscle, the pH fell during ES by 0.67 ± 0.11 units and pH 6.0 was subsequently reached in 0.7 hr compared with 5.2 hr for the controls. Half the initial ATP had disappeared by the time pH 6.19 was reached. This pH was reached in 0.4 hr in ES muscles and in 4.15 hr in the controls. The triceps brachii (TB) pH decline was monitored in a few cases in this study, and was not as greatly affected by ES as the LD or BF muscles. Although the pH of the TB fell by 0.5 units during ES, the subsequent rate of pH decline was somewhat slower than the control.

Devine (1976) reported on variation of the electrical parameters, temperature, and the delay between slaughter and ES on the rate of rigor onset in beef carcasses. These studies involved the sterno-mandibularis (S) muscle excised from beef carcasses immediately post exsanguination. Delay between bleeding and ES varied from 10 min to 3 hr. Muscle temperatures ranged from 15 to 40°C. Muscles were pulsed with reducing voltage intensity for 2 or 3 min. Electrical parameters were 50 Hz, 150-190 V, and 0.45 A of AC current, modified to produce 20% of the potentially available energy. An initial pH fall of 0.5 units occurred during ES, followed by a continuous fall after ES, which was approximately 50% faster than unstimulated muscle. The rate of pH decline was not altered by intermittent or continuous ES. Delays from 10 min to 2.5 hr postmortem did not change the pattern or extent of pH decline during ES, provided the temperature of the muscle was maintained at 35 to 37°C.

Bendall et al. (1976) investigated the effects of voltage, frequency of pulses, and pulse duration in both intact undressed beef carcasses immediately after slaughter, and in dressed sides within 60 min of slaughter. A pulse generator was used which could develop peak voltages of 30 to 700 V at a maximum of 6 A with the top half of the main AC sine wave being employed. Frequency of ES could be varied between 1 and 25 Hz. A burst of pulses of one polarity was given for 30 sec, followed by another of opposite polarity and so on, for 2 min, to avoid polarization of the electrode metal. Authors reported the ES voltage had a highly significant effect on the immediate pH fall during ES and on the subsequent rate of decline. Optimum voltage was

700 V where none of the muscles (SM, BF, LD, TB) took more than 1.1 hr to reach pH 6.0, or more than 2 hr to reach pH 5.7 at 16°C. Equivalent times were 7 and 9 hr without ES. The difference between 700 and 300 V was slight. These workers found that, when considering frequency, number of pulses, and duration of ES, the total number of pulses was most important. Identical results were obtained whether 1500 pulses were given in 1 or 2 min (i.e. at 25 Hz or 12.5 Hz), and also in a limited number of experiments with 3000 pulses, given either in 2 or 4 min. The BF and TB muscles gave the same results whether the carcasses were ES with 1500 or 3000 pulses, whereas 1500 pulses were relatively ineffective in the LD and SM muscles. Authors concluded that this was perhaps due to the more complex innervation of the latter muscles, or because of higher resistance in the electrical pathway to them. There were no differences in pH or in subsequent rate of pH fall between LD, BF and SS muscles from ES undressed carcasses and those from dressed sides and only slight differences in the TB and SM muscles with counterparts from undressed sides having somewhat faster pH decline. The pH values of 6.0 and 5.7 were reached in 8.5 and 10.5 hr, respectively, in muscles from unstimulated carcasses, and in 1.0 and 1.5-2.0 hr, respectively, in muscles from stimulated undressed carcasses.

Shaw and Walker (1977) investigated the effect of low voltage ES on beef muscle pH decline rates. In one experiment, ES was started 35 min postmortem. Pulsed direct current (40 pulses per sec, pulse width 2 msec) with varied duration (4, 2 or 1 min) and voltage (20 to 110 V) with maximum current of 500 mA was used. Within any one side,

ES or control, all muscles had similar pH declines, and the rates of pH decline were not greatly affected by the duration of ES. The pH values at 1, 4 and 24 hr postmortem were significantly lower for muscles from ES sides. In a second experiment, Shaw and Walker (1977) applied 21 V of pulsed direct current (10 pulses per sec, pulse width 2 msec) for 4 min. ES had a significant effect on 1, 4 and 24 hr postmortem pH values, with ES muscles (SM, BF, LD, TB and vastus lateralis (VL)) being lower than unstimulated counterparts. They concluded that voltages in the range of 20-110 V were as effective in accelerating glycolysis as were voltages in excess of 1000 V.

Savell et al. (1979) reported that ES of heavy weight beef carcasses within 1 hr postmortem with 100 V (440 V potential difference between electrodes), 5 A, 60 Hz, 50 impulses of 1.0 sec duration and 0.5-1.0 sec between pulses significantly accelerated pH decline in the LD at 1 and 6 hr postmortem. ES and unstimulated muscles were at pH 6.7 and 7.0, respectively, at 1 hr postmortem and were at pH 5.8 and 6.1, respectively, at 6 hr postmortem.

George et al. (1980) ES beef carcasses 1 hr postmortem with 700 peak volts, 25 pulses per sec for 2 min, with reversal of electrode polarity each 30 sec. ES accelerated pH decline in both LD and ST muscles relative to unstimulated controls. The ES LD and ST reached pH 6.0 in 1.5 and 2.1 hr, respectively, while the unstimulated muscles reached that pH in 5.9 and 7.1 hr, respectively.

McCollum and Henrickson (1977) ES beef carcasses 1 hr postmortem for 30 min duration or at 30 min postmortem for 15 min. A pulse generator delivered a direct current square wave pulse, with a frequency

of 400 cycles per sec, and a duration of 0.5 msec. Voltage rapidly increased to 300 V and remained at that level until ES was concluded. Following 30 min of ES the LD and SM exhibited significantly lower pH readings in the ES muscles when compared to muscles from unstimulated carcasses. The ES LD reached pH 6.0 in 3 hr and the ES SM in 4 hr postmortem. The unstimulated LD and SM reached pH 6.0 in 6 and 10 hr, respectively. pH of the PM was not affected by ES. The SS from ES sides differed significantly in pH from the unstimulated controls only at the 4 hr postmortem sampling period. Muscles ES 15 min behaved in much the same manner as those ES 30 min. The ES LD had reached pH 6.0 in 2 hr postmortem while its unstimulated control required 6 hr. The SM showed the same pattern observed for the 30 min ES period. The SS responded to a greater degree, perhaps because ES initiated 30 min instead of 60 min postmortem allowed for a greater glycogen supply in the musculature. Workers concluded that reduction of ES duration from 30 to 15 min and time of ES postmortem from 60 min to 30 min did not affect the relative rate of pH decline in the ES sides.

Davey et al. (1976) ES one side of beef carcasses 30 min postmortem for 1-2 min. Electrical pulses of alternating polarity were used to ES the sides. Voltage on the open circuit was 3600 V and pulse frequency was 15 Hz. The voltage was load dependent, and on ES the voltage decreased to approximately 1600 V, at which time the system delivered about 2 A. Without ES, the pH of the muscles declined slowly, and by 8 hr had decreased by no more than 0.2 pH units. The period of ES induced an immediate and very rapid fall in pH, the extent of which was roughly determined by the ES duration. The time course of

pH decline after ES also seemed to be somewhat increased. In carcasses ES for 1 min or more, the pH of the LD had fallen below 6.0 by 5 hr postmortem and was within approximately 0.3 pH units of the ultimate. Muscles from unstimulated carcasses had hardly approached their ultimate pH by 24 hr postmortem.

Demeyer et al. (1980) ES beef sides 45 min postmortem using the top half of an alternating current, giving pulsed direct current of 50 Hz with a pulse width of 10 msec. Average currents of 100 mA, 200 mA and 600 mA were applied consecutively for 80 sec, giving voltages of 15-100 V equivalent to 200-300 V (peak). Workers monitored pH declines in the LD, ST, GM, TB, infraspinatus (IS) and tensor faciae (TF) muscles. They found the average time after ES necessary to reach pH 6.0 was reduced from 4.8 hr to 2.0 hr for muscles from unstimulated and ES carcasses, respectively.

Effect on Tenderness

Several workers have reported that ES shortly after slaughter caused a subsequent increase in tenderness of some muscles (Bouton et al., 1980b; Dutson et al., 1980; Riley et al., 1980). Dutson et al. (1980) and Smith et al. (1980), in summaries of Texas A&M studies, reported that reductions in LD SFV for samples from ES carcasses generally were large when control samples had large SFV. There was a similar trend, though not as consistent, for sensory panel tenderness ratings. Hence, they suggested that ES was of greatest benefit for use on carcasses that would produce less tender meat if untreated.

Carcasses that were likely to produce inherently tender meat were improved but to a lesser extent.

The increase in tenderness of muscles from ES carcasses may result from the minimization of cold shortening. Chrystall and Hagyard (1975) evaluated tenderness of muscles from lamb carcasses stimulated for 55 sec with sinusoidal pulses of 5 msec duration, 15 Hz and 3600 V. They reported that ES lamb frozen 60 min postmortem and roasted from the frozen state did not suffer from cold and thaw shortening. All SFV differences between treatment groups for the corresponding muscles (LD, BF, SM, GM, QF and adductor (A)) were highly significant, with muscles from ES carcasses having smaller SFV than controls.

Davey et al. (1976) ES beef sides with 3600 V at 40 min postmortem and boned carcasses at 24 hr after 2°C chilling. Some cuts were frozen immediately and some were stored for 48 hr at 10°C and then frozen. Fast chilling of the LD from unstimulated carcasses caused pronounced cold shortening with much and highly variable toughening. They reported that ES had a marked effect in preventing the development of toughness due to rapid chilling. They concluded that ES speeds glycolysis throughout the musculature of beef carcasses and that rigor is reached well before temperatures fall to levels inducing cold shortening. Tenderness was the eating quality most affected by ES. The taste panel found that LD muscles from ES carcasses were significantly more tender than unstimulated controls, both unaged and aged. Taste panel results showed similar tenderness trends for the rump (BF and GM), but the SM was unaffected by ES.

Carse (1973) evaluated the tenderness (SFV) of four lamb muscles from ES and control paired sides. Muscles from each of the five ES sides, delayed 5 hr before entering the freezer, were more tender than samples from the control sides. ES before early freezing significantly prevented toughening.

Measurement of the amount of shortening in muscles from ES carcasses, by determination of sarcomere length, revealed that differences in shortening between ES and non-stimulated sides do not exist in most cases (Savell et al., 1977a, 1979; Smith et al., 1977, 1979a; Seideman et al., 1979; Demeyer et al., 1980; George et al., 1980; Will et al., 1980). However, differences in sarcomere length have occasionally been noted (Smith et al., 1977, 1979a).

Tenderness increases in ES carcasses may be attributed to increased lysosomal enzyme activity. Savell et al. (1977a) reported that LD muscles from ES beef sides and lamb carcasses had significantly higher (more tender) taste panel tenderness ratings and lower Warner-Bratzler SFV (more tender) than unstimulated controls. However, no differences were found in sarcomere lengths between muscles from ES or unstimulated carcasses. The tenderness increase was explained by a relatively lower pH at a higher temperature, disruption of lysosomal membrane and the concurrent release of acid hydrolases into the muscle tissue of ES muscles. Dutson et al. (1977), Bowling et al. (1978) and George et al. (1980) observed similar results in lamb, beef and calf carcasses.

Savell et al. (1978) suggested that ES may also improve tenderness by physical disruption due to the formation of contracture bands.

George et al. (1980) and Will et al. (1980) have made similar observations of structural alterations in ES muscle.

Judge et al. (1980) reported that ES may alter the thermal stability of collagen. Beef sides were ES within 45 min postmortem with 20 pulses of 2 sec duration separated by 1 sec intervals. The output of the stimulator was an AC of 60 cycles per sec and 480 V with initial amperage of 3.5 A falling to approximately 2.0 A at the conclusion of ES. The ES treatment was found to lower the thermal stability of the perimysial collagen. The perimysium includes a significant proportion of Type III collagen, the major cross-links of which are heat stable hydroxylysino-5-keto-norleucine bonds (Bailey and Sims, 1977). Since electrical stimulation reduced the heat stability of the collagen, the possibility of a treatment induced disruption of some of these cross-links seems feasible. Some of the effects of ES could therefore be the result of subtle changes in the degree of collagen cross-linking reflected as small reductions in thermal stability and substantial improvements in meat tenderness.

Electrical Stimulation and Hot Boning

Precautions must be considered when hot boning because of tenderness problems associated with rapid chilling or freezing of pre-rigor excised muscle. In addition to the approaches outlined in the hot-boning discussion, ES has been utilized to help reduce the severity or incidence of those tenderness problems. The use of ES should allow early boning of carcasses by increasing the rate of glycolysis and rigor mortis onset in postmortem muscle.

Gilbert and Davey (1976) utilized a 3600 V stimulus to accelerate glycolysis in beef carcasses. As indicated by pH determinations, ES carcasses had achieved rigor in 5 hr postmortem and they concluded that it was possible to bone the carcasses without risk of cold shortening despite subsequent rapid chilling or freezing. This was confirmed by taste panel reactions to the cooked product. They stated that tenderness of unaged cuts transferred immediately to the freezer is the eating characteristic most likely to be affected by the HB treatment. Cuts from ES sides boned at 5 hr and subsequently frozen had a moderate to high degree of tenderness. They concluded that ES reduced the need for conventional chilling to achieve carcass setting, overcame cold and thaw shortening, and still permitted additional tenderizing from aging. These workers suggested, to minimize bacterial growth and to harden fat for easy handling during boning, the sides should be chilled during the required 4-5 hr delay before cutting. They concluded that the temperature of the meat would not fall sufficiently in that time for cold shortening to occur.

Gilbert et al. (1977) ES beef sides 60 min after bleeding for 2 min with 3600 V and HB them at 2 hr postmortem. Except for the fillet, unstimulated, unaged cuts had larger SFV and were less uniform in tenderness than their ES counterparts. Taste panel scores confirmed this. Authors concluded that HB cuts from ES carcasses aged before freezing attained a high and uniform degree of tenderness. They also concluded that the major potential of carcass ES followed by HB lies in reduction of the chilling and aging period to 2 days from the 10-20 days often used commercially.

Will et al. (1976) ES beef sides at 30 min postmortem with 300 V for a 15 min duration and HB muscles at 3, 5 or 7 hr postmortem. Sarcomere lengths from all muscles studied (LD, PM, SM and ST) indicated no significant differences between the samples from control and ES sides. SFV and taste panel data taken from the same muscles (Pierce, 1977) showed increased tenderness in muscles from ES HB sides of beef when compared to the control.

Bouton et al. (1980b) used three voltage systems: 1100 V, 110 V and 45 V at 25-45 min postmortem. All treatments except the extra low voltage treatment caused a significant and substantial reduction in pH values at 1.25 hr postmortem in SM, BF, VL, LD and TB muscles. The mean 4 hr pH values for all ES treatments were below 6.0 and in some cases were close to the 22 hr pH values for LD, BF and VL muscles. Authors reported that, based on Warner-Bratzler SFV, muscles removed at 1 or 2 hr postmortem, then subjected to conditions which induce cold shortening, the 1100 V system was superior to the other two. Lower SFV for individual muscles from ES sides were usually accompanied by longer sarcomeres than for control samples, and these workers suggested that the major effect of ES is the prevention of cold shortening.

Nichols and Cross (1980) studied the effects of ES combined with HB on pH decline. ES carcasses were treated at approximately 1 hr postmortem with a continuous 1 amp current (AC-60 cycles) for 2 min. Voltage ranged from about 140 to 200 V. LD muscles were sampled for pH determinations at 6, 10, 21 and 30 hr postmortem. As compared with muscles from nonstimulated carcasses, pH of ES LD muscles fell quickly

until 6 hr postmortem. These workers found no differences between sarcomere lengths in the LD excised at 1, 2 or 4 hr postmortem.

Kastner et al. (1980) ES beef sides with 400-600 V at 1 hr postmortem and HB muscles at 2 hr postmortem. LD samples from this treatment aged (2°C) until 6 days postmortem were equal in SFV and taste panel tenderness to LD samples from sides conventionally chilled at 2°C for 48 hr. However, SM controls were more tender than ES and HB counterparts.

Taylor et al. (1980) ES beef sides at 50 min postmortem with 700 V at 25 pulses/sec for four 30 sec periods. Muscles were HB at 1-2 hr postmortem and were rapidly chilled at -1°C until 24 hr postmortem. When compared with control muscles, those ES and HB exhibited no treatment differences in eating quality.

Corte et al. (1980) ES sides from Zebu cows at 30 min postmortem with 700 V, intermittent AC, 60 Hz for a 2 min duration. Muscles were HB at 45 min postmortem and were either chilled at 2°C for 5 days postmortem or were frozen at -40°C and stored at -20°C for 3 months. In the ES, HB cuts, the muscle pH reached 6.1 in 1-1.5 hr postmortem. In control sides, it took more than 8 hr to reach that pH. LD muscles from ES and HB sides, both chilled and frozen, were significantly more tender than the controls. Only the chilled ES and HB SM muscles were significantly more tender than the controls and the BF steaks were equal for all treatments.

Blade Tenderization

Technology for increasing tenderness of meat cuts exists in the form of mechanical tenderization techniques developed and used extensively in the HRI meat trade (Davis et al., 1977). Blade or needle tenderization (BT) can be used to improve the tenderness of beef (Savell et al., 1977b; Hayward et al., 1980). Miller (1975) stated four benefits or justifications for using mechanical tenderization: 1) it insures tenderness of normal table-grade cuts; 2) it equalizes tenderness in portioned items containing two or more muscles of differing tenderness; 3) it up-grades cuts not previously utilized for steaking without enzymatic tenderization; and 4) BT is more uniform and more easily controlled than enzyme treatments which require more floor space and clean up.

Generally, BT has been found to significantly reduce Warner-Bratzler SFV in a variety of cooked meat cuts (Davies et al., 1975; Bowling et al., 1976; Smith et al., 1979a; Hayward et al., 1980). In some cases, sensory panel tenderness ratings are also found to be significantly improved by BT (Davies et al., 1975; Davis et al., 1977; Smith et al., 1979b). However, increased tenderness as indicated by Warner-Bratzler SFV is not necessarily supported by taste panel tenderness values. Davies et al. (1975) stated that BT, unaged beef loin steaks had lower Warner-Bratzler SFV than their non-tenderized counterparts aged 12 and 16 days. However, taste panel evaluations indicated that the non-tenderized aged steaks were more tender. Bowling et al. (1976), Seideman et al. (1977) and Tatum et al. (1978)

have reported that shear force data may over-estimate the real effects of BT in increasing organoleptic tenderness. Bowling et al. (1977) postulated that this may be a result of the shear blade following the fracture plane or path created by tenderizer blades.

BT effects on cooking characteristics are somewhat disputed. Generally it is agreed that BT does not affect cooking loss (Savell et al., 1977b; Tatum et al., 1978; Raccach and Henrickson, 1979; Smith et al., 1979b). Davis et al. (1977) and Hayward et al. (1980) reported increased cooking losses in BT cuts as compared with control samples, and Davis et al. (1977) suggested that the increased cooking losses might be due to moisture losses through the holes made by the blades or by changes in heat transfer properties of the meat. Differences may also be due to differential cooking rates and/or failure to adequately monitor and point temperatures (Smith et al., 1979b). Seideman et al. (1977) reported greater thaw losses from BT cuts as opposed to control cuts while Savell et al. (1977b) reported no differences.

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Chapter III

BEEF CARCASS ELECTRICAL STIMULATION AND HOT BONING EFFECTS ON PSOAS MAJOR AND TRICEPS BRACHII MUSCLES

ABSTRACT

Forty-six steer carcasses were used to evaluate Warner-Bratzler shears and cooking losses of triceps brachii (TB) and psoas major (PM) muscles from sides assigned to three treatments: 1) conventionally chilled at 2 to 4°C for 48 hr (C); 2) hot boned at 2 hr postmortem (HB); and 3) electrically stimulated at 1 hr postmortem (400-600 V, 60 Hz of AC current with approximately 1.0 amp continuously delivered through the carcass for 2 min) and hot boned at 2 hr postmortem (ESHB). Steaks were removed immediately after muscle excision and after 6 days aging. Steaks were cooked from the frozen or thawed state and some steaks were blade tenderized. HB and ESHB TB steaks cut after muscle excision had higher shear forces than C counterparts for steaks cooked frozen or thawed. Shear forces of C, HB, and ESHB groups for vacuum-aged (blade tenderized and non-blade tenderized) TB steaks were not different ($P > .05$). PM steaks from HB and ESHB groups cut after muscle excision and cooked thawed, and those vacuum-aged (blade tenderized and non-blade tenderized) had lower ($P < .05$) shear forces than C counterparts. Shear forces for PM steaks cut after

muscle excision and cooked frozen were similar for all three treatments. Cooking losses for C, HB, and ESHB groups were similar for all steaks and muscles. Blade tenderization decreased shear force means but did not change the relative differences among treatments. Electrical stimulation did not improve the HB technique, and the TB muscle required aging for HB to be successful.

Introduction

Current beef processing technology involves animal slaughter, carcass chilling, then carcass fabrication. An alternate process, termed hot boning (HB) or hot processing, is gaining increased interest because of potential economic benefits (Kastner, 1977; Cuthbertson, 1979; Kansas State University, 1980). HB is the fabrication of carcasses soon after slaughter and before conventional chilling, thus excess fat and bone are not chilled. Careful processing techniques must be utilized because muscle excised and chilled or frozen before the onset of rigor mortis can significantly toughen due to the effects of prerigor excision, cold shortening or thaw rigor (Locker and Hagyard, 1963; Marsh et al., 1968; Marsh, 1972; Davey and Gilbert, 1974).

Steaks and roasts of equal or superior quality (yield, color, tenderness and flavor) compared with that conventionally processed have been obtained when muscles and muscle systems have been excised within 1 to 2 hr postmortem, then vacuum packaged and conditioned until 24 or 48 hr postmortem at 15°C or aged until 8 days postmortem at 1°C (Schmidt and Gilbert, 1970; Schmidt and Keman, 1974). Alternatively, carcasses have been conditioned at 15 to 16°C for 6 to 10 hr postmortem, then HB (Kastner et al., 1973; Kastner and Russell, 1975; Kastner et al., 1976). Combinations of these approaches have also been used (Dransfield et al., 1976).

Electrical stimulation (ES) of beef carcasses postmortem can accelerate the onset of rigor mortis (Carse, 1973). Therefore, use

of ES may reduce or eliminate the carcass or muscle conditioning or aging periods required for successful HB (Gilbert et al., 1977). Several researchers have evaluated the use of ES to facilitate HB of beef carcasses (Gilbert and Davey, 1976; Gilbert et al., 1977; Will et al., 1976; Bouton et al., 1980; Kastner et al., 1980; Nichols and Cross, 1980).

The objective of this study was to evaluate shear force values (SFV) and some cooking characteristics of ESHB and HB triceps brachii (TB) and psoas major (PM) beef muscles and the effects of blade tenderization (BT) on those treatments.

Materials and Methods

Forty-six crossbred steers were obtained from R. L. Hruska U. S. Meat Animal Research Center at Clay Center, Nebraska. Steers were of two body types: 24 Hereford x Angus (medium size body type (MT)) and 22 Simmental sired steers from either Chianina x Angus or Chianina x Hereford females (large size body type (LT)). Steers were purchased at 8 mo of age and averaged 257.6 kg. They were finished on either an accelerated (ACC) or a conventional (CONV) feeding regimen. The ACC regimen consisted of a 4 week, high-roughage adjustment phase followed by a high concentrate finishing phase. The CONV feeding regimen consisted of a 4 week, high-roughage adjustment phase, a backgrounding phase and a high concentrate finishing phase.

Cattle on the ACC regimen were fed for 140 and 182 days (MT and LT, respectively) and weighted 430 and 505 kg, respectively. At these weights both types of cattle should have about 5 percent

longissimus dorsi lipid (Koch et al., 1976), which is equivalent to the low Choice U.S.D.A. quality grade.

MT and LT cattle on the CONV regimen were fed for 258 and 306 days, respectively. The slaughter weights of 522 and 591 kg were chosen to simulate weights at which these types of cattle would be slaughtered by the industry.

Steers were slaughtered in four groups at the Kansas State University Meat Laboratory. The MT ACC group was slaughtered first, the LT ACC group 42 days later, MT CONV 118 days later and LT CONV 166 days later. These are hereafter designated as slaughter groups. U.S.D.A. quality grades ranged from low Good to low Choice.

Cattle were stunned, exsanguinated, skinned, eviscerated and split into sides. Kidney fat was removed from all sides during the dressing procedure. The right side of each carcass was ES at 1 hr postmortem and was HB at 2 hr postmortem (ESHB). The electrical stimulus was applied for a 2 min duration with 400 to 600 volts (V), and 60 hertz (Hz) of alternating current with approximately 1.0 amp (A) continuously delivered through the carcass. Probes were inserted on the inside of the rear leg approximately 8 cm below the attachment of the Achilles tendon and laterally along the humerus.

The left side of each carcass was assigned to one of two treatments: a conventional manner of processing, chilled at 2 to 4°C until 48 hr postmortem (C) or HB at 2 hr postmortem (HB) (Figure 1).

The TB, long head, and PM muscles were excised (ESHB and HB at 2 hr; C at 48 hr postmortem) and two steaks (2.5 cm) were removed from each. These steaks were immediately frozen at -26°C until

LEFT SIDE	RIGHT SIDE
CONTROL - (C) SIDES CHILLED AT 2-4°C UNTIL 48 HR POSTMORTEM N = 23 HOT BONED - (HB) HOT BONED AT 2 HR POSTMORTEM N = 23	ELECTRICALLY STIMULATED AND HOT BONED - (ESHB) ELECTRICALLY STIMULATED AT 1 HR POSTMORTEM, 2 MIN, 400-600 V, 60 HZ, 1 AMP, HOT BONED AT 2 HR POSTMORTEM N = 46

Figure 1 - Assignment of treatments to carcass sides

evaluated. The remaining muscle portions were vacuum packaged and stored in cardboard boxes at 1 to 5°C until 6 days postmortem.

Temperature data were collected for the TB, long head, at 2, 4, 6, 8 and 24 hr postmortem. Samples for pH determination were obtained from the PM and TB, lateral head, at 1, 2, 4, 6, 8 and 24 hr postmortem. Muscle samples were removed from the TB with a 1.27 cm coring device, and thin strips were excised from the anterior end of the PM. A 1 to 2 g muscle sample was blended with 10 ml of 5 mM NaIAc in 150 mM KCl (Bendall, 1973).

At 6 days postmortem, one steak (2.5 cm) was cut from each muscle, wrapped in freezer paper and stored at -26°C until evaluated. The remaining muscle portion was passed once through a Ross blade tenderizer. An additional steak (2.5 cm) was removed, wrapped in freezer paper and stored at -26°C until evaluated.

One steak removed immediately after muscle excision was cooked from the frozen state. All exterior fat was removed from the frozen steak and weights were recorded before and after cooking to determine percentage weight loss. Other steaks were trimmed of exterior fat while frozen, weighed, then thawed at 2°C for 15 to 16 hr prior to cooking. Steaks were reweighed before and after cooking to obtain percentage thaw, cooking and combined losses. Percentage thaw loss was calculated by dividing thawed weight by frozen weight x 100. Percentage cooking loss was calculated by dividing cooked weight by thawed weight x 100. Percentage combined loss was calculated by dividing cooked weight by frozen weight x 100.

Steaks were cooked according to AMSA (1978) guidelines in a 163°C gas oven to an internal temperature of 70°C. After cooling at room temperature for 2 hr, shear samples were removed perpendicular to the steak surface by using a drill press equipped with a 1.27 cm diameter coring device (Kastner and Henrickson, 1969). Six cores were obtained per steak and each core was sheared once with a Warner-Bratzler shearing apparatus.

Statistical Analysis

The experimental design was a split-split plot design. The whole plot experimental unit was an animal, with the treatments applied to the whole plot being: 1) time of slaughter confounded with management (MT ACC, LT ACC, MT CONV and LT CONV) and 2) treatments applied to the sides of an animal, being either C paired with ESHB, or HB paired with ESHB. At no time was C paired with HB. Note that for every C or HB treatment, two ESHB treatments were observed. The sub plot experimental unit was the side of an animal with treatments applied to the sub plot being the treatments applied to sides as previously discussed. The sub-sub plot experimental unit was a steak, with the treatments applied to the sub-sub plot being the postmortem handling of the muscles and steaks.

An analysis of variance was performed and where there was a significant ($\alpha = .05$) slaughter by treatment interaction, mean comparisons were made within each slaughter group. Where there was no significant interaction, treatment mean comparisons were made averaging over slaughter groups.

Because the sides of an animal were treated as either C versus ESHB or HB versus ESHB, there were two different types of treatment comparisons which could be made: a within animal comparison and a between animal comparison or two different between animal comparisons.

The C versus ESHB and HB versus ESHB comparisons were made using both the within and between animal comparisons. The C versus HB comparison was made using two between animal comparisons; one using just the C and HB sides and one using the animal totals.

A linear model technique was used in making the treatment comparisons, where the observed comparison vector had an assumed normal distribution with a constant mean vector and covariance matrix defined for the different types of comparisons used. It was then tested at the $\alpha = .05$ level if this constant mean vector was equal to the zero vector, which was the case when the treatments were not significantly different. If the above test indicated the constant mean vector not to be the zero vector, this would then imply that the treatments were significantly different. In this event, claims concerning the relative magnitude of the treatment means are based on the observed order of the sample means.

Results and Discussion

Temperature and pH Data

Postmortem pH and temperature declines of the TB muscle are shown in Figures 2 and 3, respectively. Carcass ES increased the rate of pH decline in the TB muscle compared with the C and HB treatments. A pH

Figure 2 - Postmortem pH declines for the triceps brachii by carcass treatment

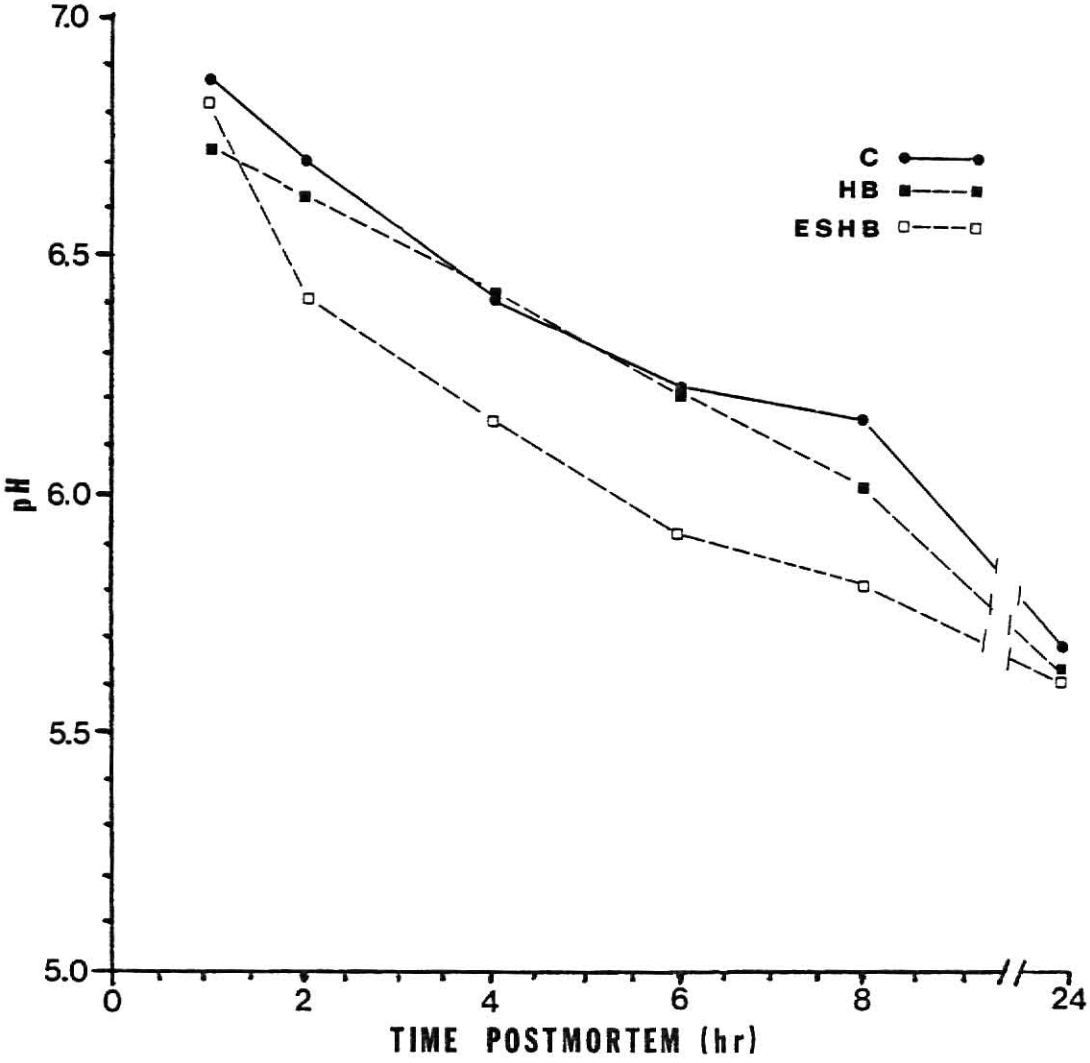
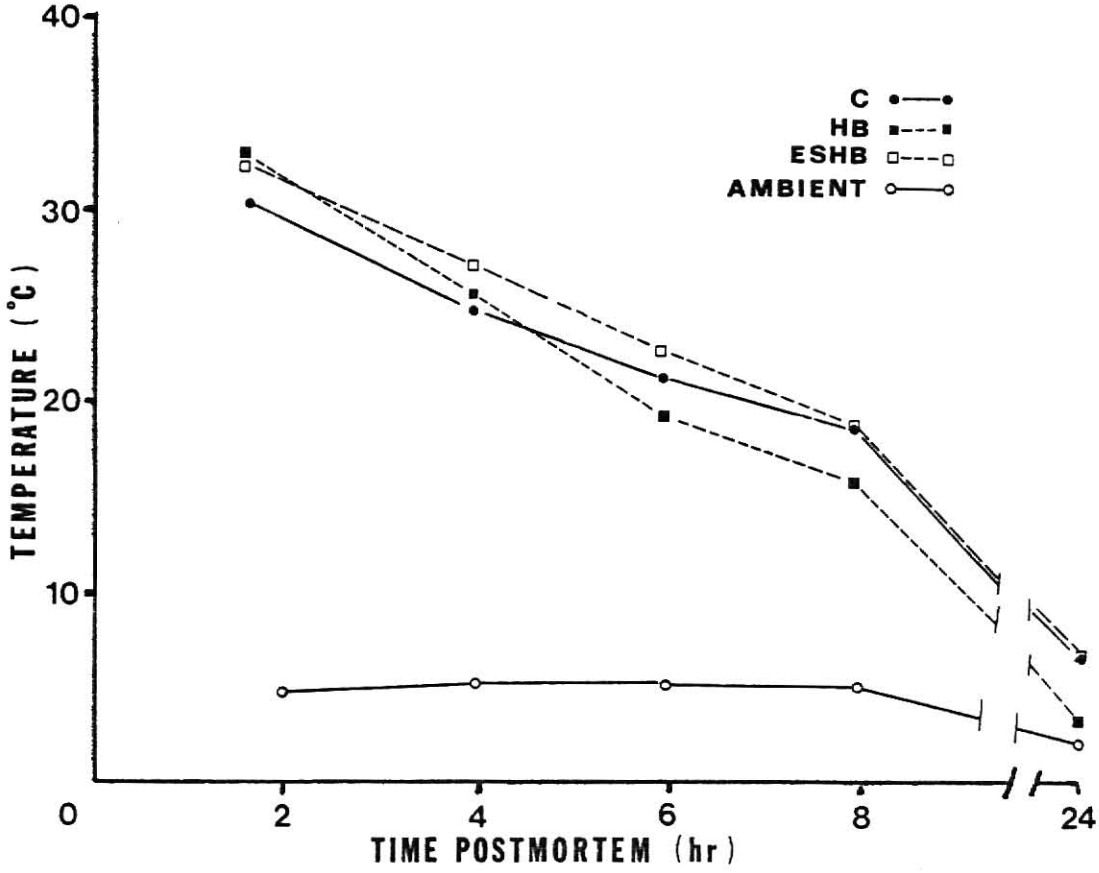

7.0
6.5
6.0
5.5
5.0
pH
0
2
4
6
8
24
TIME POSTMORTEM (hr)
C
HB
ESHB

Figure 3 - Postmortem temperature declines for the triceps brachii by carcass treatment


40
30
20
10
0
TEMPERATURE (°C)
C
HB
ESHB
AMBIENT
2
4
6
8
24
TIME POSTMORTEM (hr)

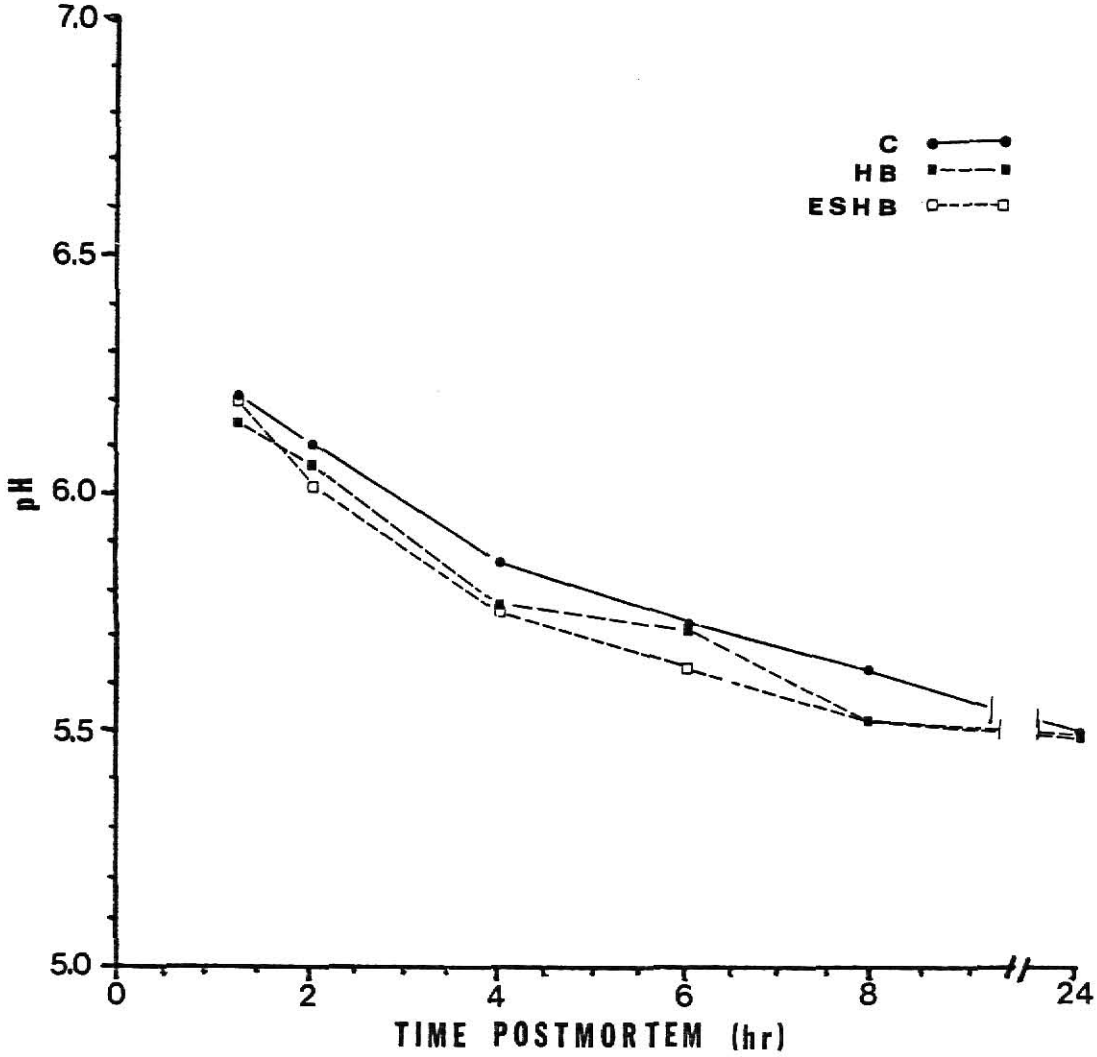
of 6.0 was reached approximately 5 hr postmortem in the ESHB TB as opposed to more than 8 hr in the C and HB muscles. Bendall et al. (1976) reported that ES beef TB muscle reached pH 6.0 in 2.5 hr when using 700 V, 25 Hz for 2 min administered at 45 min postmortem. The HB TB muscles had a slightly faster rate of pH decline than the C, with the HB pH at 8 hr being 6.02, while the C TB was 6.2. This slight increase may have been due to the temperature of the HB muscle being higher than the C at 2, 3 and 4 hr postmortem (2.2, 1.6, 1.1°C higher, respectively). This is supported by Newbold and Harris (1972).

The postmortem pH decline of the PM muscle is shown in Figure 4. The ESHB PM muscle reached pH 6.0 at 2 hr postmortem while the HB and C were at that pH between 2 to 3 hr postmortem; therefore, electrical stimulation appeared to somewhat accelerate the rate of postmortem pH decline in the PM. It should be noted that the 1 hr postmortem PM pH values for all treatments were relatively low (6.1 to 6.2). Davey et al. (1976) reported an accelerated pH decline in the PM when using 3600 V, 15 Hz, 2 A delivered 30 min postmortem for 30 sec to 10 min duration. However, McCollum and Henrickson (1977) found no significant differences in pH decline between ES and non-stimulated PM (stimulation time 1 hr postmortem, for 30 min duration, using 300 V at 400 Hz).

Shear Force Comparisons for C, HB, and ESHB Treatments

Steaks removed upon muscle excision then frozen. Bendall and Rhodes (1976) reported that rapid cooling of muscles to 2°C can be started without danger of cold shortening as soon as pH 6.0 is reached

Figure 4 - Postmortem pH declines for the psoas major by carcass treatment


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

and rapid freezing without danger of thaw shortening at pH 5.7. SFV from steaks frozen prerigor and cooked from the frozen state should reflect cold shortening and thaw rigor shortening because of the rapid thawing associated with cooking from the frozen state (Perry, 1950). However, thaw rigor can be avoided by thawing slowly so the structures remaining frozen provide sufficient restraint to prevent thaw shortening (Chrystall, 1976; Marsh et al., 1968).

In this study, the HB and ESHB TB steaks excised at 2 hr postmortem were placed in the freezer at no later than 3 hr postmortem (pH values were at 6.53 and 6.27, respectively). These steaks were frozen within 60 min after being placed in the freezer. HB and ESHB TB steaks treated in this manner and cooked from the frozen state had higher SFV (were less tender) than C counterparts excised at 48 hr postmortem and cooked from the frozen state. Differences were significant ($P < .05$) in 6 of 8 comparisons (Table 1). Those HB and ESHB TB steaks that were removed 2 hr postmortem and thawed before cooking also had higher SFV than C counterparts; however, differences were generally of less magnitude than in steaks cooked frozen and were only of statistical significance in 3 of 8 comparisons (Table 1). Cold shortening may have had an influence on HB and ESHB TB steaks in both cases (cooking from frozen or thawed state), while the thawing procedure may have reduced any effect of thaw rigor shortening. C TB muscles chilled in the carcass did not reach 10°C within 10 hr postmortem nor before pH 6.0 was attained (Figs. 2 and 3); therefore, cold shortening should not have been a problem with C TB samples (Locker and Hagyard, 1963; Chrystall, 1976).

Table 1. Triceps brachii Warner-Bratzler shear force (kg) mean comparisons within slaughter group for carcass treatments by steak treatments.

Slaughter group	Carcass treatment	Steak treatment: Removed upon muscle excision[a] cooked frozen	Steak treatment: Removed upon muscle excision[a] cooked thawed	Steak treatment: Aged[b], non-BT	Steak treatment: Aged[b], BT
MT ACC	C	3.43	2.83[f]	3.57	2.75
	HB	3.75	3.95	4.18	4.02
	ESHB[c]	4.05	4.81	3.81	4.03
	ESHB[d]	3.80	4.33	4.00	3.64
MT CONV	C	3.45[ef]	3.40	2.92	2.79
	HB	6.60	4.80	3.35	3.73
	ESHB[c]	6.03	4.82	3.57	3.27
	ESHB[d]	5.32	4.22	3.43	3.61
LT ACC	C	3.69[ef]	3.78[ef]	3.70	2.59
	HB	6.18	5.77	4.11	3.36
	ESHB[c]	5.72	6.03	4.04	3.21
	ESHB[d]	5.10	5.39	3.83	3.15
LT CONV	C	4.21[ef]	3.63	3.40	2.62
	HB	7.09	4.18	3.93	3.47
	ESHB[c]	7.48	4.74	3.51	2.49
	ESHB[d]	7.32	4.23	3.77	3.22

[a] HB and ESHB steaks cut at 2 hr postmortem then frozen; C steaks cut at 48 hr postmortem then frozen.

[b] Muscles aged until 6 days postmortem.

[c] ESHB paired with C.

[d] ESHB paired with HB.

[e] C vs HB comparison within slaughter group by steak treatment, means differ ($P < .05$).

[f] C vs ESHB comparison within slaughter group by steak treatment, means differ ($P < .05$); all other treatment mean comparisons within slaughter group by steak treatment do not differ ($P > .05$).

When comparing HB to ESHB, all shear force mean comparisons for the TB muscle were similar (Table 1). This indicates that even though ES accelerated pH decline of the TB muscle (Fig. 2), steaks from ESHB TB muscles were still frozen in a prerigor condition (pH 6.27 at 3 hr postmortem) as were HB counterparts (pH 6.53 at 3 hr postmortem).

HB and ESHB PM steaks excised at 2 hr postmortem were at pH 5.92 and 5.86, respectively (Fig. 4) when placed in the freezer (3 hr postmortem). Those steaks cooked frozen had similar ($P > .05$) SFV to C counterparts, while ESHB SFV were lower ($P < .05$) than HB SFV (Table 2). This indicates that ES may have accelerated glycolysis enough to minimize any effects of thaw rigor. Some degree of thaw rigor may have occurred in the HB steaks cooked from the frozen state, because HB and ESHB comparisons made for those steaks thawed prior to cooking revealed HB and ESHB steak SFV to be equal (Table 2). HB and ESHB steaks cooked thawed were more tender than C possibly because HB and ESHB steaks were frozen pre-rigor, and thawed slowly, such that the frozen structure restrained contraction relative to C. This effect may have been accented by our method of pH sampling which may have allowed the C PM muscle to contract more than in an unsampled side where the PM is restrained. The PM muscle can be removed 2 hr postmortem, with or without prior ES without adversely affecting SFV (tenderness). Even though steaks from the PM muscle may have suffered from effects of pre-rigor excision, cold shortening or thaw rigor, the effect did not appear of practical significance, particularly when considering the magnitude of the SFV.

Table 2. Psoas major Warner-Bratzler shear force (kg) mean comparisons for carcass treatments by steak treatments, pooled over all slaughter groups.

Carcass treatment	Steak treatment			
	Removed upon muscle excision[a] cooked frozen	Removed upon muscle excision[a] cooked thawed	Aged[b], non-BT	Aged[b], BT
C	3.10	3.20[ef]	2.88[ef]	2.77[ef]
HB	3.40[g]	2.63	2.33	1.98
ESHB[c]	2.81	2.68	2.33	2.36
ESHB[d]	3.01	2.68	2.34	2.08

[a]HB and ESHB steaks cut at 2 hr postmortem then frozen; C steaks cut at 48 hr postmortem then frozen.

[b]Muscles aged until 6 days postmortem.

[c]ESHB paired with C.

[d]ESHB paired with HB.

[e]C vs HB comparison within steak treatment, means differ ($P < .05$).

[f]C vs ESHB comparison within steak treatment, means differ ($P < .05$).

[g]HB vs ESHB comparison within steak treatment, means differ ($P < .05$); all other treatment mean comparisons within steak treatment do not differ ($P > .05$).

Steaks aged 6 days postmortem, non-blade tenderized. Those steaks from TB muscles aged at 1 to 5°C until 6 days postmortem had statistically equal SFV regardless of treatment (Table 1). These results agree with results of Schmidt and Keman (1976) who reported similar ($P > .05$) SFV for HB (1 hr postmortem) and cold boned (48 hr postmortem) steaks (LD, PM and gluteus medius) and roasts (semitendinosus, semimembranosus, biceps femoris and quadriceps femoris) aged at 1°C for 7 days. Aging HB and ESHB TB muscles alleviated shear force differences when each were compared to C. Aging HB and ESHB TB muscles in a box at higher initial temperatures (Fig. 3) than C for the first 4 hr postmortem may have helped insure these results. ES did not appear to facilitate the HB of steaks subsequently aged because all HB versus ESHB comparisons were non-significant.

ESHB and HB PM steaks from muscles aged 6 days postmortem had lower SFV than C counterparts (Table 2). HB and ESHB PM steak SFV were similar ($P > .05$), indicating that ES did not facilitate the HB technique. Since kidney fat was removed from C sides, it is possible that the rate of temperature decline was faster in the unprotected PM muscle on the C side than that of the HB and ESHB PM muscle chilled in a box. A faster chilling rate may have led to some degree of cold shortening. Cold shortening should not be extensive in the PM muscle stretched in the normally suspended carcass; however, our method of pH sampling may have allowed relatively more contraction than in an unsampled side. Additionally, slower chilling of HB and ESHB muscles in a box could have accelerated the conditioning process relative to C counterparts chilled

on the carcass. No temperature data were collected on the PM muscle to substantiate these theories, but the C TB chilled slightly faster than the boxed HB and ESHB TB muscles during the first 4 hr postmortem (Fig. 3).

Steaks aged 6 days postmortem, blade tenderized. SFV for BT TB and PM steaks are reported in Tables 1 and 2, respectively. Mean values were generally lowered by BT relative to non-BT counterparts; however, the relative SFV differences between carcass treatments remained similar ($P > .05$). This indicates that the influence of BT on SFV was not affected by carcass treatment.

Steaks from BT HB and ESHB muscles aged until 6 days postmortem were compared with non-BT C counterparts aged 6 days postmortem to determine if BT would result in a more tender product. TB results (Table 3) indicate that steak SFV comparisons were statistically equal. Even though BT had generally lowered SFV for all carcass treatments (Table 1), the change was not of great enough magnitude to create a difference ($P > .05$) between HB and ESHB BT and C non-BT TB steaks. Aged BT HB and ESHB PM steak SFV were smaller than the C non-BT aged steaks (Table 3). However, non-BT HB and ESHB steaks had lower SFV than C counterparts (Table 2) so BT was not necessarily needed to improve the tenderness of the PM as this muscle is inherently of acceptable tenderness.

Thaw, Cooking, and Combined Losses

HB and ESHB TB steaks removed 2 hr postmortem and cooked after thawing had significantly lower thaw losses than C counterparts

Table 3. Triceps brachii and psoas major Warner-Bratzler shear force mean comparisons.

Slaughter group	Carcass and steak treatment			
	C	HB	ESHB[b]	ESHB[c]
	Aged[a], non-BT	Aged[a], BT	Aged[a], BT	Aged[a], BT
Triceps brachii - within slaughter group for carcass and steak treatments[d]				
MT ACC	3.56	4.02	4.03	3.64
MT CONV	2.92	3.73	3.27	3.61
LT ACC	3.70	3.36	3.21	3.15
LT CONV	3.40	3.47	2.49	3.22
Psoas major - for carcass and steak treatments pooled over all slaughter groups				
	2.88[e]	1.98	2.36	2.08

[a]Muscles aged until 6 days postmortem.

[b]ESHB paired with C.

[c]ESHB paired with HB.

[d]All C vs HB and C vs ESHB mean comparisons within slaughter group for Triceps brachii do not differ ($P > .05$).

[e]C vs HB and C vs ESHB comparisons for Psoas major, means differ ($P < .05$).

(Table 4). Because the HB and ESHB TB steaks were frozen in a pre-rigor condition (within 3 hr postmortem), the pH and thus water holding capacity was higher than C steaks which had reached their ultimate pH at the time of freezing. It should be noted that even though thaw losses were less for ESHB and HB TB steaks when removed prerigor, frozen and cooked thawed combined weight losses (total includes thaw and cooking loss) were similar for all treatments (Table 4). TB steaks from muscles aged until 6 days postmortem (non-tenderized) had similar ($P > .05$) thaw loss, regardless of treatment, indicating that the pH's and water holding capacities had equalized during the aging period. Cooking and combined weight losses for these steaks were also similar, regardless of treatment.

Cooking data for PM, shown in Tables 4, 5 and 6, indicate that thaw, cooking, and combined loss comparisons between C, HB, and ESHB treatments were generally statistically equal regardless of the steak treatment.

Both HB and ESHB BT TB steaks had significantly higher percentage thaw losses than C counterparts (Table 4). But percentage cooking and combined loss means were equal for all carcass treatment comparisons. Furthermore, PM percentage thaw, cooking and combined loss means were similar for all carcass treatment comparisons (Tables 4, 5 and 6). When HB and ESHB BT steaks were compared with C non-BT steaks, the BT steaks had significantly higher thaw losses than those non-BT steaks; however, cooking and combined losses were similar ($P > .05$). This was true for both TB and PM steaks (Table 7). Results reported in the literature generally agree that drip and cooking losses are

Table 4. Triceps brachii percentage thaw, cooking and combined loss and psoas major percentage thaw loss mean comparisons for carcass treatments by steak treatments pooled over all slaughter groups.

		Steak treatment			
Triceps brachii	Carcass treatment	Removed upon muscle excision[a] cooked frozen	Removed upon muscle excision[a] cooked thawed	Aged[b], non-BT	Aged[b], BT
Thaw loss, %	C	-----	2.64[ef]	2.84	4.34[ef]
	HB	-----	1.31	2.53	5.53
	ESHB[c]	-----	1.31	3.45	6.11
	ESHB[d]	-----	1.56	2.42	5.16
Cooking loss, %	C	-----	32.09	30.34	29.37
	HB	-----	30.18	29.98	29.48
	ESHB[c]	-----	30.40	29.15	30.38
	ESHB[d]	-----	28.05	30.02	30.03
Combined loss, %	C	30.91	33.86[f]	32.30	32.42
	HB	32.94	31.09	31.70	32.93
	ESHB[c]	32.47	31.29	31.57	34.60
	ESHB[d]	31.74	29.15	31.70	33.63
Psoas major					
Thaw loss, %	C	-----	2.44	3.87	4.09
	HB	-----	1.83	5.25	5.62
	ESHB[c]	-----	1.96	4.27	4.92
	ESHB[d]	-----	1.84	4.40	5.20

[a]HB and ESHB steaks cut at 2 hr postmortem then frozen; C steaks cut at 48 hr postmortem then frozen.

[b]Muscles aged until 6 days postmortem.

[c]ESHB paired with C.

[d]ESHB paired with HB.

[e]C vs HB comparison within steak treatment, means differ ($P < .05$).

[f]C vs ESHB comparison within steak treatment, means differ ($P < .05$); all other treatment mean comparisons within steak treatment do not differ ($P > .05$).

Table 5. Psoas major percentage cooking loss mean comparisons within slaughter group for carcass treatments by steak treatments.

Slaughter group	Carcass treatments	Steak treatment: Removed upon muscle excision[a] cooked thawed	Steak treatment: Aged[b], non-BT	Steak treatment: Aged[b], BT
MT ACC	C	26.94	30.24	29.65
	HB	27.96	27.43	28.24
	ESHB[c]	26.48	29.77	28.57
	ESHB[d]	27.83	29.03	28.77
MT CONV	C	27.55[e]	28.75	32.93
	HB	27.73	26.71	30.53
	ESHB[c]	24.74	28.19	30.64
	ESHB[d]	23.38	28.43	30.67
LT ACC	C	28.35	28.90	29.20
	HB	23.93	29.89	31.18
	ESHB[c]	28.19	28.46	31.12
	ESHB[d]	24.84	31.01	30.22
LT CONV	C	29.42	30.11	31.64
	HB	26.59	31.06	30.19
	ESHB[c]	27.25	29.16	33.20
	ESHB[d]	28.59	31.73	31.86

[a]HB and ESHB steaks cut at 2 hr postmortem then frozen; C steaks cut at 48 hr postmortem then frozen.

[b]Muscles aged until 6 days postmortem.

[c]ESHB paired with C.

[d]ESHB paired with HB.

[e]HB vs ESHB comparison within slaughter group by steak treatment, means differ ($P < .05$); all other treatment mean comparisons within slaughter group by steak treatment do not differ ($P > .05$).

Table 6. Psoas major percentage combined loss mean comparisons[e] within slaughter group for carcass treatments by steak treatments.

Slaughter group	Carcass treatment	Steak treatment: Removed upon muscle excision[a] cooked frozen	Steak treatment: Removed upon muscle excision[a] cooked thawed	Steak treatment: Aged[b], non-BT	Steak treatment: Aged[b], BT
MT ACC	C	28.53	29.30	34.32	33.39
	HB	28.95	29.75	31.44	32.89
	ESHB[c]	24.71	28.09	33.63	32.96
	ESHB[d]	31.24	29.26	32.58	32.96
MT CONV	C	27.64	29.48	31.60	35.47
	HB	31.50	29.55	30.43	33.62
	ESHB[c]	28.61	26.89	31.60	33.97
	ESHB[d]	27.92	25.71	31.49	33.57
LT ACC	C	29.98	29.67	30.91	32.15
	HB	25.94	25.06	33.72	34.84
	ESHB[c]	28.86	29.13	31.16	34.48
	ESHB[d]	25.80	26.04	33.44	33.92
LT CONV	C	29.34	30.83	31.90	33.57
	HB	34.86	27.07	34.42	34.57
	ESHB[c]	28.76	28.25	31.25	35.58
	ESHB[d]	32.74	29.00	35.07	35.55

[a]HB and ESHB steaks cut at 2 hr postmortem then frozen; C steaks cut at 48 hr postmortem then frozen.

[b]Muscles aged until 6 days postmortem.

[c]ESHB paired with C.

[d]ESHB paired with HB.

[e]All treatment mean comparisons within slaughter group by steak treatment do not differ ($P > .05$).

Table 7. Triceps brachii and psoas major percentage thaw, cooking and combined mean comparisons.

	Carcass and steak treatment			
	C Aged[a], non-BT	HB Aged[a], BT	ESHB[b] Aged[a], BT	ESHB[c] Aged[a], BT
Triceps brachii - for carcass and steak treatments pooled over all slaughter groups				
Thaw loss, %	2.84[ef]	5.53	6.11	5.16
Cooking loss, %	30.34	29.48	30.38	30.03
Combined loss, %	32.30	32.93	34.60	33.63
Psoas major - for carcass and steak treatments pooled over all slaughter groups				
Thaw loss, %	3.87[ef]	5.62	4.92	5.20
Psoas major - within slaughter groups for carcass and steak treatments				
Cooking loss, %				
MT ACC	30.24	28.24	28.57	28.77
MT CONV	28.75	30.53	30.64	30.67
LT ACC	28.90	31.18	31.12	30.22
LT CONV	30.11	30.19	33.20	31.86

Table 7. (Continued)

	Carcass and steak treatment			
	C	HB	ESHB[b]	ESHB[c]
	Aged[a], non-BT	Aged[a], BT	Aged[a], BT	Aged[a], BT
Psoas major - within slaughter group for carcass and steak treatments				
Combined loss, %				
MT ACC	34.32	32.89	32.96	32.96
MT CONV	31.60	33.62	33.97	33.57
LT ACC	30.91	34.84	34.48	33.92
LT CONV	31.90	34.57	35.58	35.55

[a]Muscles aged until 6 days postmortem.

[b]ESHB paired with C.

[c]ESHB paired with HB.

[d]C vs HB comparison, means differ ($P < .05$).

[e]C vs ESHB comparison, means differ ($P < .05$); all other treatment mean comparisons do not differ ($P > .05$).

similar between BT and non-tenderized steaks (Bowling et al., 1976; Savell et al., 1977; Seideman et al., 1977; Tatum et al., 1978; Smith et al., 1979; Raccach and Henrickson, 1979).

Conclusions

HB the PM at 2 hr postmortem proved successful without an aging period, but the TB treated in a similar manner had higher SFV than those conventionally processed, particularly when cooked from the frozen state.

HB at 2 hr postmortem combined with 6 days of vacuum aging resulted in SFV and cooking characteristics for TB and PM steaks equal or superior to C counterparts. This practice appears to coincide well with the current trend in marketing boxed beef.

ES increased the rate of glycolysis in both PM and TB muscles. However, since data for HB and ESHB steaks were similar, the earlier onset of rigor in the ESHB muscles did not facilitate the HB of those muscles. Even though BT generally lowered SFV, it did not improve the HB technique.

Additional research is needed to examine other HB practices to determine the parameters required for optimal HB of subprimals or retail cuts at a centralized facility.

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Chapter IV

APPENDIX

Statistical Analysis

The experimental design was a split-split plot design (Figure 5). The whole plot experimental unit was an animal, with the treatments applied to the whole plot being: 1) the time of slaughter confounded with management factors (these termed slaughter groups (slghgp)); and 2) the treatments applied to the sides of an animal, being either control (C) paired with electrically stimulated and hot boned (ESHB) or hot boned (HB) paired with ESHB (these termed treatment combinations (trtco)). The sub plot experimental unit was the side of an animal, with treatments applied to the sub plot being the treatments applied to sides as previously discussed. The sub-sub plot experimental unit was a steak (stk), with the treatments applied to the sub-sub plot being the postmortem handling of the muscles and steaks.

The model used was:

$$Y_{ijktm} = \mu_{ijkt} + b_{ijm} + c_{ijkm} + e_{ijktm}$$

where: i = slghgp = 1, 2, 3, 4

j = trtco = 1(C-ESHB), 2(HB-ESHB)

k = trt(trtco) = 1(2), 3(3)

t = stk = 1, 2, 3, 4

m = animal = 1, 2, ... n_{ij}

$n_1 = n_2 = n_3 = 6$

$n_4 = 5$

and where:

b_{ijm} ~ independent identically distributed $N(0, \sigma_b^2)$

(within slghgp-trtco between animal variation)

c_{ijkm} ~ independent identically distributed $N(0, \sigma_c^2)$

(within slghgp-trtco-animal between trt(trtco) variation

e_{ijktm} ~ independent identically distributed $N(0, \sigma^2)$

(within slghgp-trtco-trt(trtco)-animal between stk variation

An analysis of variance was performed and for each variable, where there was a significant slghgp by trt interaction, mean comparisons were made within each slghgp. Where there was no significant interaction, trt mean comparisons were made averaging over slghgp.

The ANOVA table:

source	degrees of freedom
whole plot:	
slghgp	3
trtco	1
slghgp x trtco	3
error (whole)	38
sub plot:	
trt (trtco)	2
trt (trtco) x slghgp	6
error (sub)	38
sub-sub plot:	
stk	3
stk x slghgp	9
stk x trt (trtco)	6
stk x slghgp x trt (trtco)	18
error	240

The whole plot error variance was:

$$\text{Var}\left[\bar{Y}_{ij}\ldots\right] = \text{Var}\left[\frac{1}{2\cdot 4\cdot n_{ij}} \sum_{k=1}^{2}\sum_{t=1}^{4}\sum_{m=1}^{n_{ij}} Y_{ijktm}\right]$$

$$= \frac{1}{(8n_{ij})^2}\ \text{Var}\left[\sum_{k=1}^{2}\sum_{t=1}^{4}\sum_{m=1}^{n_{ij}}\left(\mu_{ijkt} + b_{ijm} + c_{ijkm} + e_{ijktm}\right)\right]$$

$$= \frac{1}{8n_{ij}}\left\{8\sigma_b^2 + 4\sigma_c^2 + \sigma^2\right\}$$

The sub plot error variance was:

$$\text{Var}\left[\bar{Y}_{ijk\cdots} - \bar{Y}_{ijk'..}\right]$$

$$= \frac{1}{(4n_{ij})^2}\ \text{Var}\left[\sum_{t=1}^{4}\sum_{m=1}^{n_{ij}}\left(\mu_{ijkt} + b_{ijm} + c_{ijkm} + e_{ijktm}\right.\right.$$

$$\left.\left. - \mu_{ijk't} - b_{ijm} - c_{ijk'm} - e_{ijk'tm}\right)\right] = \frac{1}{2}\, n_{ij}\left\{4\sigma_c^2 + \sigma^2\right\}$$

The sub-sub plot error variance was:

$$\text{Var}\left[\bar{Y}_{ijkt.} - \bar{Y}_{ijkt'.}\right]$$

$$= \frac{1}{n_{ij}^2}\ \text{Var}\left[\sum_{m=1}^{n_{ij}}\left(\mu_{ijkt} + b_{ijm} + c_{ijkm} + e_{ijktm}\right.\right.$$

$$\left.\left. - \mu_{ijkt'} - b_{ijm} - c_{ijkm} - e_{ijkt'm}\right)\right] = \frac{2}{n_{ij}}\left\{\sigma^2\right\}$$

Because the sides of an animal were treated as either C versus ESHB or HB versus ESHB, there were two different types of trt comparisons which could be made; a within animal comparison and a between animal comparison or two different between animal comparisons.

The C versus ESHB and HB versus ESHB comparisons were made using both the within and between animal comparisons. The C versus HB comparison was made using two between animal comparisons; one using just the C and HB sides and one using the animal totals.

An example of the type of comparison made:
C versus ESHB comparison made at trt x slghgp x stk level.

$$H_o : \mu_{ij1t} - \mu_{ij3t} = 0 \quad \text{and} \quad \mu_{ij1t} - \mu_{ij'3t} = 0$$

$$H_A : \mu_{ij1t} - \mu_{ij3t} \neq 0 \quad \text{and} \quad \mu_{ij1t} - \mu_{ij'3t} \neq 0$$

Contrasts to test these hypotheses are:

$$\bar{Y}_{ij1t.} - \bar{Y}_{ij3t.} \quad \text{and} \quad \bar{Y}_{ij1t.} - \bar{Y}_{ij'3t.}$$

The expected values of these contrasts:

i) $$E\left[\bar{Y}_{ij1t.} - \bar{Y}_{ij3t.}\right] = \mu_{ij1t} - \mu_{ij3t}$$

ii) similarly $$E\left[\bar{Y}_{ij1t.} - \bar{Y}_{ij'3t.}\right] = \mu_{ij1t} - \mu_{ij'3t}$$

The variances of these contrasts:

$$\text{i)}\quad \text{Var}\left[\bar{Y}_{ijlt.} - \bar{Y}_{ij3t.}\right] = \frac{2}{n_{ij}}\left[\sigma_c^2 + \sigma^2\right]$$

$$\text{ii)}\quad \text{Var}\left[\bar{Y}_{ijlt.} - \bar{Y}_{ij'3t.}\right] = \frac{2}{n_{ij}}\left[\sigma_b^2 + \sigma_c^2 + \sigma^2\right]$$

The covariance between the two contrasts:

$$\text{Cov}\left[\bar{Y}_{ijlt.} - \bar{Y}_{ij3t.}\,,\ \bar{Y}_{ijlt.} - \bar{Y}_{ij'3t.}\right] = \frac{1}{n_{ij}}\left[\sigma_c^2 + \sigma^2\right]$$

Estimation of quantities of variance and covariance:

$$\text{remember}\quad \text{MSE (whole)} = 8\sigma_b^2 + 4\sigma_c^2 + \sigma^2$$

$$\text{MSE (sub)} = 4\sigma_c^2 + \sigma^2$$

$$\text{MSE (sub-sub)} = \sigma^2$$

$$\text{Var}\left[\bar{Y}_{ijlt.} - \bar{Y}_{ij3t.}\right] = \frac{2}{n_{ij}}\left[\sigma_c^2 + \sigma^2\right]$$

$$= \frac{2}{n_{ij}}\left[\frac{\text{MSE(sub)} + 3\ \text{MSE(sub-sub)}}{4}\right]$$

$$\text{Var}\left[\bar{Y}_{ijlt.} - \bar{Y}_{ij'3t.}\right] = \frac{2}{n_{ij}}\left[\sigma_b^2 + \sigma_c^2 + \sigma^2\right]$$

$$= \frac{2}{n_{ij}}\left[\frac{\text{MSE(whole)} + \text{MSE(sub)} + 6\ \text{MSE (sub-sub)}}{8}\right]$$

$$\text{Cov}\left[\bar{Y}_{ijlt.} - \bar{Y}_{ij3t.}\,,\ \bar{Y}_{ijlt.} - \bar{Y}_{ij'3t.}\right] = \frac{1}{n_{ij}}\left[\sigma_c^2 + \sigma^2\right]$$

$$= \frac{1}{n_{ij}}\left[\frac{\text{MSE(sub)} + 3\ \text{MSE(sub-sub)}}{4}\right]$$

The following model was used to analyze

$$\begin{bmatrix} \bar{Y}_{ij1t.} - \bar{Y}_{ij3t.} \\ \bar{Y}_{ij1t.} - \bar{Y}_{ij'3t.} \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \end{bmatrix} \mu + \begin{bmatrix} e_1 \\ e_2 \end{bmatrix}$$

where: $\underline{e} = \begin{bmatrix} e_1 \\ e_2 \end{bmatrix}$ in the random error vector

assume $\underline{e} \sim N(\underline{0}, \Sigma)$

$$\Sigma_{2x2} = \begin{bmatrix} \text{Var}\left(\bar{Y}_{ij1t.} - \bar{Y}_{ij'3t.}\right) & \text{Cov}\left(\bar{Y}_{ij1t.} - \bar{Y}_{ij3t.}\,,\, \bar{Y}_{ij1t.} - \bar{Y}_{ij'3t.}\right) \\ \text{Cov}\left(\bar{Y}_{ij1t.} - \bar{Y}_{ij3t.}\,,\, \bar{Y}_{ij1t.} - \bar{Y}_{ij'3t.}\right) & \text{Var}\left(\bar{Y}_{ij1t.} - \bar{Y}_{ij'3t.}\right) \end{bmatrix}$$

$$\hat{\mu} = \left([1 \;,\; 1]\, \hat{\Sigma}^{-1} \begin{bmatrix} 1 \\ 1 \end{bmatrix} \right)^{-1} \left([1 \;,\; 1]\, \hat{\Sigma}^{-1} \begin{bmatrix} \bar{Y}_{ij1t.} - \bar{Y}_{ij3t.} \\ \bar{Y}_{ij1t.} - \bar{Y}_{ij'3t.} \end{bmatrix} \right)$$

result: $\hat{\mu} \sim N\left(\mu, \left([1 \;,\; 1]\, \hat{\Sigma}^{-1} \begin{bmatrix} 1 \\ 1 \end{bmatrix} \right)^{-1}\right)$

to test H_o^* : $\mu = 0$ versus H_A^* : $\mu \neq 0$

$$\frac{\hat{\mu} - \mu}{\sqrt{\left([1 \;,\; 1]\, \hat{\Sigma}^{-1} \begin{bmatrix} 1 \\ 1 \end{bmatrix} \right)^{-1}}} \sim N(0,1) \text{ asymptotically}$$

when: H_o^* is true, $\mu = 0$, therefore when H_o^* is true

$$\frac{\hat{\mu}}{\sqrt{\left([1\ ,\ 1]\ \hat{\Sigma}^{-1}\begin{bmatrix}1\\1\end{bmatrix}\right)^{-1}}} \sim N(0,1)$$

thus reject H_o^* , and thus reject H_o , if

$$\frac{\hat{\mu}}{\sqrt{\left([1\ ,\ 1]\ \hat{\Sigma}^{-1}\begin{bmatrix}1\\1\end{bmatrix}\right)^{-1}}} > Z_\alpha$$ where Z_α is found from the normal

tables for a given α-level of significance.

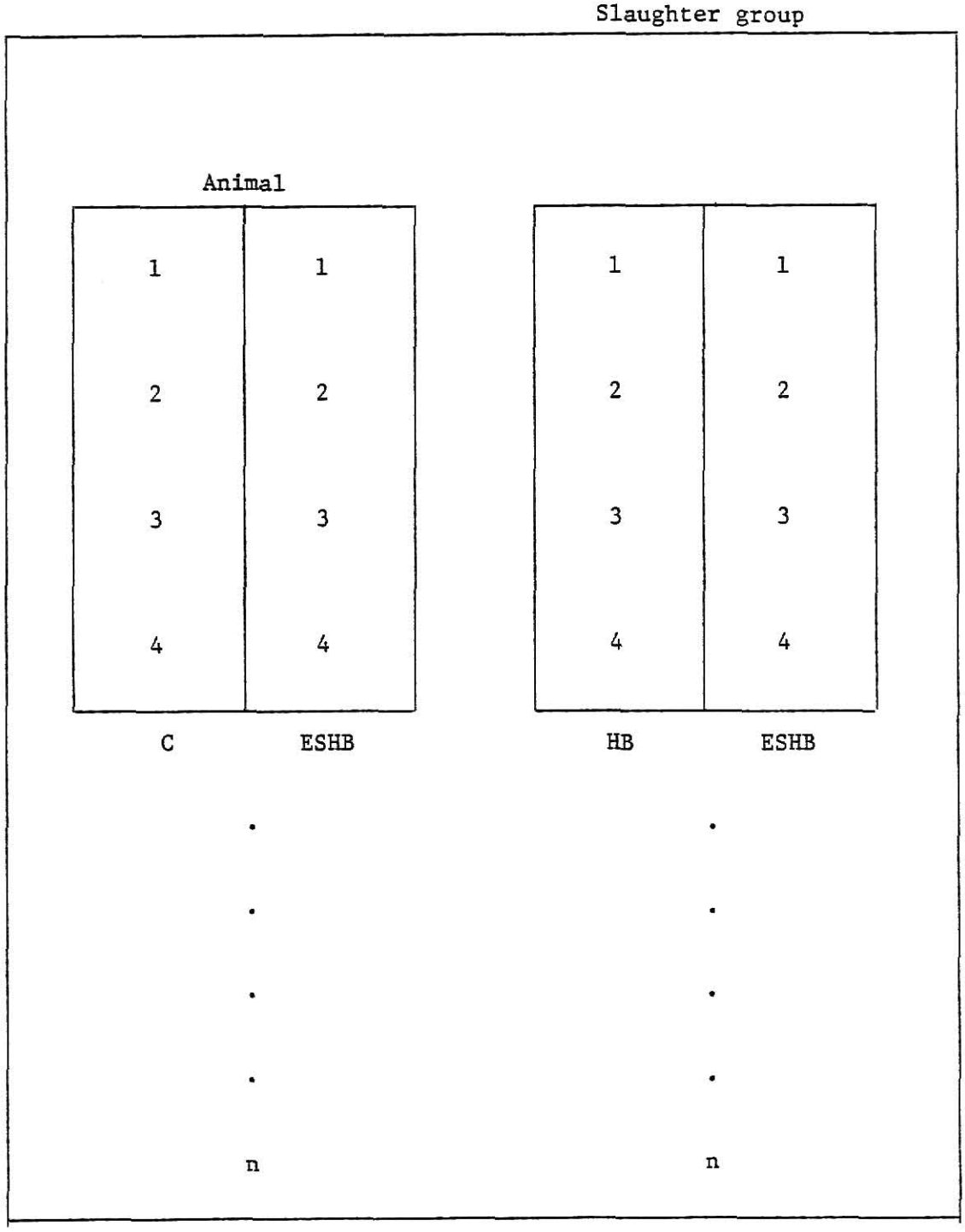

Figure 5 - Experimental design

Table 8. Degrees of freedom and mean squares for Warner-Bratzler shear force means, thaw, cooking and combined loss percentages by muscle.

Muscle	Warner-Bratzler shear force d.f.	Warner-Bratzler shear force M.S.	Thaw loss percentage d.f.	Thaw loss percentage M.S.	Cooking loss percentage d.f.	Cooking loss percentage M.S.	Combined loss percentage d.f.	Combined loss percentage M.S.
Triceps brachii								
whole plot	38	146.22	38	32.67	38	366.94	38	733.86
sub plot	38	22.30	38	4.81	38	42.46	38	49.85
sub-sub plot	240	3.53	160	2.46	160	11.11	240	13.90
Psoas major								
whole plot	38	39.13	38	39.07	38	108.84	38	267.29
sub plot	38	6.09	38	6.49	38	20.12	38	34.12
sub-sub plot	240	1.58	160	2.18	160	5.51	240	8.47

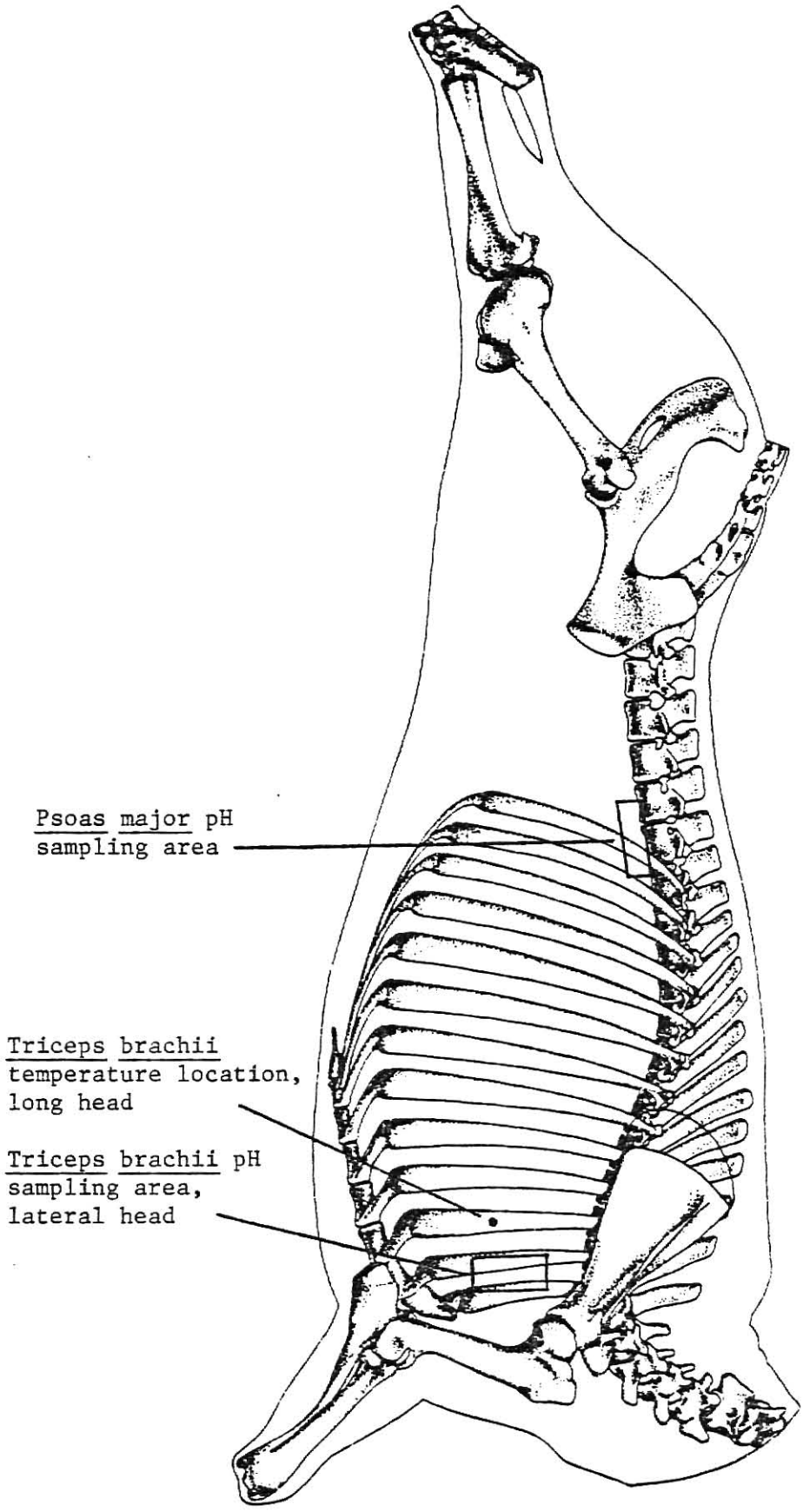

Figure 6 - Temperature and pH sampling locations

POSTERIOR PSOAS MAJOR OR SHANK END CLOD

Steak removed at time of muscle excision; frozen -26°C cooked from frozen state 2.5 cm
Steak removed at time of muscle excision; frozen -26°C cooked from thawed state 2.5 cm
7.5 cm
Steak from muscle aged until 6 days postmortem; frozen -26°C non-blade tenderized 2.5 cm
Steak from muscle aged until 6 days postmortem; blade tenderized; frozen -26°C 2.5 cm

ANTERIOR PSOAS MAJOR OR RIB END CLOD

Figure 7 - Sampling arrangement for test muscles

BEEF CARCASS ELECTRICAL STIMULATION AND HOT BONING EFFECTS ON PSOAS MAJOR AND TRICEPS BRACHII MUSCLES

by

MARY LYON

B.S., California Polytechnic State University
San Luis Obispo, 1978

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Forty-six steer carcasses were used to evaluate Warner-Bratzler shears and cooking losses of triceps brachii (TB) and psoas major (PM) muscles from sides assigned to three treatments: 1) conventionally chilled at 2 to 4°C for 48 hr (C); 2) hot boned at 2 hr postmortem (HB); and 3) electrically stimulated at 1 hr postmortem (400-600 V, 60 Hz of AC current with approximately 1.0 amp continuously delivered through the carcass for 2 min) and hot boned at 2 hr postmortem (ESHB). Steaks were removed immediately after muscle excision and after 6 days aging. Steaks were cooked from the frozen or thawed state and some steaks were blade tenderized. HB and ESHB TB steaks cut after muscle excision had higher shear forces than C counterparts for steaks cooked frozen or thawed. Shear forces of C, HB, and ESHB groups for vacuum-aged (blade tenderized and non-blade tenderized) TB steaks were not different ($P > .05$). PM steaks from HB and ESHB groups cut after muscle excision and cooked thawed and those vacuum-aged (blade tenderized and non-blade tenderized) had lower ($P < .05$) shear forces than C counterparts. Shear forces for PM steaks cut after muscle excision and cooked frozen were similar for all three treatments. Cooking losses for C, HB, and ESHB groups were similar for all steaks and muscles. Blade tenderization decreased shear force means but did not change the relative differences among treatments. Electrical stimulation did not improve the HB technique, and the TB muscle required aging for HB to be successful.