THE EFFECT OF ELECTRICAL CURRENT ON HOT BONED PORK QUALITY

By

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ON HOT BONED PORK QUALITY

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CHAPTER I

INTRODUCTION

In recent years the rising cost of labor and energy has forced the meat industry to search for new and different processing methods. The meat industry has adopted more efficient processing methods such as portion control and centralized processing, which are both energy saving and labor reducing processes. Newest more efficient fabrication method in comparison with conventional processing is "hot" processing, which is the fabrication of a carcass prior to chilling. This process gives rise to "box" beef, which is also space and energy saving.

Research and implementation of accelerated processing or "hot" boning process is moving ahead at a fast pace to study its effectiveness. Reddy (1962) studied the tenderness of muscles processed pre-rigor. Examination of "hot" processing pork became prominent by 1969 (Barbe et al., 1966; Barbe and Henrickson, 1967; Mandigo and Henrickson, 1966; Henrickson, 1968). "Hot" processing was found to be equal or of superior quality in cured ham after evaluating bacterial count, yield, tenderness, juiciness, flavor, and moisture content (Mandigo and Henrickson, 1966; Henrickson, 1968).

The main advantages of "hot" boning proposed by Henrickson in 1974 were commercially significant. Among these are less energy required to chill just the edible tissue and not the excess bone and fat, also reduced microbial contamination if properly handled, less refrigeration

facilities, less space for storage, and lower transportation cost in boxed cuts of meat. Accelerated processing of the pork carcass immediately following slaughter into primal and processed cuts, was studied by Mandigo et al. (1978). These carcasses were processed into primal cuts within 1 hour of slaughter and the conventional was chilled for 24 hours before processing. After chilling and tempering, no significant differences were found in yields between the two processing methods.

Tenderness of meat is the most important attribute of eating quality to a consumer. Tenderness of pork is not as large a factor since the majority of pork goes into cured products and the effect of cold-shortening is only one-tenth that of beef and lamb.

The objective of this study was to examine the possibility of improving pork quality hot processed by implementing the use of electrical current post-mortem.

CHAPTER II

REVIEW OF LITERATURE

Hot Processing

One of the earliest studies concerned with the removal of muscle soon after slaughter was by Ramsbottom and Strandine (1949) who investigated the effect of boning beef before chilling on quality. One of their hypotheses was to show a faster rate of chilling in the form of boneless cuts, rather than as sides. Research team confirmed their hypothesis in tests made on two choice grade carcasses and two commercial grade carcasses. Loin section which was excised about one hour following slaughter demonstrated a maximum temperature difference of 10-15^{o}F lower as compared to the bone-in loins at two to eight hours post-mortem.

Tenderness of beef boned before chilling was estimated on broiled steaks cut from the Longissimus Dorsi at three, six, nine, and twelve days post-mortem. Muscles which were excised prior to chilling were less tender than those that remained on the carcass until chilled. Beef cooked at 2 hours was more tender than at 2 days, after which time the meat became increasingly more tender.

Reddy (1962) reported that prerigor processed bovine muscle had a decrease in tenderness in the Semitendinosus muscle, but the Gluteus medius and Longissimus Dorsi did not increase nor decrease in

tenderness. Trautman (1964) found that pork muscle processed pre-rigor had more emulsifying capacity and salt-proteins than post-rigor muscle.

Pulliam and Kelly (1965) found that hams which were "hot" processed were found to have higher bacterial counts than in conventionally processed hams when evaluated prior to smoking, but after smoking bacterial counts were low in both groups. In contrast, Barbe et al. (1966) and Barbe and Henrickson (1967) found less total bacterial contamination in "hot" processed ham and hypothesized that the "hot" processed ham being rapidly handled as compared to conventional ham gave spoilage bacteria less opportunity for growth.

Mandigo and Henrickson (1966) evaluated the yield, tenderness, juiciness, flavor, and moisture content of "hot" processed hams, cured and smoked prior to chilling. "Hot" processed hams, compared to conventional processing indicated a product of equal or superior quality. Reddy and Henrickson (1969) reported that hot ham muscles which were cured and canned exhibited less free fluids in the can, a higher moisture content, greater shear values, more nitrosopigments, and more extensive cure diffusion than cold processed ham muscles.

Fabrication of fresh pork by Henrickson (1967) to retail form prior to chilling provided cuts with quality equivalent to conventionally processed products.

Tenderness of "hot" processed pork using the Warner-Bratzler shear instrument and fiber kinkiness was reported by Henrickson (1968). Data indicated no discrimination against hot processing, however; Henrickson (1968) also noted that hot processed porcine muscle was darker than conventionally chilled muscle, but after chilling no difference could be detected between the two processes. As with pork, pre-rigor

processed beef chuck showed a greater emulsifying capacity than did the post-rigor beef according to Acton and Safle (1969).

Microbial and organoleptic properties of hot processed bovine muscles were reported by Schmidt and Gilbert (1970). They excised muscles at two hours post-mortem from six Angus steers and bulls of different maturities subsequently aged at 15°C for 24 or 48 hours and compared to control muscles excised after being held on the carcass at 9°C for 24 hours. Hot excised muscles were placed in gas impermeable bags and frozen at -14°C. Muscles aged for 24 hours particularly the Biceps Femoris and Longissimus Dorsi were shown to be similar in tenderness as compared to the controls, while hot excised muscles aged for 48 hours were significantly more tender than muscles from the control side. Control Semitendinosus had a lower shear force value than either of the treatments and there appeared to be no treatment effect on the Semimembranosus. Muscles stored for 48 hours at 15°C in a sealed gas impermeable bag had a mean bacterial count within the range of $10^2/cm^2$ to $10^5/cm^2$ of muscle surface. It was concluded from this study that pre-rigor excision of bovine muscle could produce an organoleptically and microbiologically acceptable product.

Hypothesis that hot boning the beef carcass is economically favorable was supported by Brasington and Hammons (1970). They also indicated that on-the-rail boning resulted in lower costs due to the use of semi-skilled workers during a portion of the operation. Also, higher yields were indicated along with being more flexible, sanitary, and a less tiring operation for the workers.

Kastner (1972) studied the effects of excising bovine muscles at two, five and eight hours post-mortem and compared the corresponding

side chilled for 48 hours at 2°C and then hot processed. The two processes were compared for shear force, flavor, color value, percent loss (shrink), cooking loss, percent moisture, fat, and water binding capacity. No significant differences were found in shrinkage between the two processes at the two-hour holding period, but at five and eight hours the "hot" boned side had a smaller average percent loss. Evaluation of tenderness was accomplished by the Warner-Bratzler shear instrument and the results were that the two and five hour processes were significantly less tender than their cold boned counterparts; however, no difference was found between control and the eight-hour treatments. Evaluation of the hot boned steaks for color and pressed fluid ratios were found to be statistically different from their controls at all three holding periods. Flavor and percent cooking loss was found to have no detectable difference between the three holding periods versus the 48 hour controls. It could be concluded from reported results on excision of muscles at five or eight hours post-mortem that hot boning is feasible.

Marsh et al. (1972) reported that excision of the seven muscles with cold exposure of 0°C within 20 minutes post-mortem caused significant toughening in muscle examined.

Schmidt and Keman (1974) hot boned the right side of six Angus steer carcasses at one hour post-mortem, and the boneless wholesale cuts were weighed and kept at 2°C for four hours, after which they were placed in a 1°C room overnight. They were then vacuum packaged and placed in a 7°C room for seven days. The cold boning of the left side was initiated after each side was chilled for seven days at 7°C. Comparison of shear force, flavor, juiciness, tenderness, or overall

acceptability between hot and cold boned muscles found no significant differences.

Will (1974) and Will and Henrickson (1976) removed the Biceps Femoris, Longissimus Dorsi, and Semimembranosus muscles from one side of 12 choice steers at three delayed chilling periods three, five, and seven hours at 16°C. The Biceps Femoris, Longissimus Dorsi, and Semimembranosus of the opposite side were held at 1.1°C for a 48 hour post-mortem conditioning period prior to excision. The authors examined differences among shear force and penetration values between the chilled and each delay chilled treatment. Results were that the detectable variations registered by the trained tenderness taste panel were small between the two studies. All findings indicated that hot boning of beef at all three treatments prior to chilling provided beef of satisfactory tenderness.

Kastner and Russell (1975) examined shear force, rate of pH decline, color, and flavor on bovine muscle held at 16°C and excised at six, eight, or ten hours post-mortem as compared to muscles held at 2°C and excised 48 hours after death. Flavor and color panel evaluation revealed no significant differences between any of the treatments. Tenderness of the six-hour treatment was unacceptable, but the eight- and ten-hour conditioning periods produced meat with tenderness equal to that of the control.

Evaluation by Dransfield et al. (1976) on the eating quality of hot boned beef was accomplished by excision of muscles three hours post-mortem and held at 10°C for 24 hours prior to chilling compared to muscles excised 24 hours after slaughter. Eating quality of the hot boned beef rated by consumers found the overall acceptability of "hot"

boned beef equal to that of conventionally processed beef for all cuts studied, except the flank, where the "hot" boned beef was preferred.

Kastner et al. (1976) hot boned Longissimus Dorsi muscles at six, eight, or ten hours post-mortem. Control muscle was excised after 48 hours at 2°C and results were that the hot boned muscle was more tender than conventional, but it was not statistically significant.

Mandigo et al. (1977) studied the accelerated processing of fresh pork to cured products as ham, bacon, and loin of market weight hogs. Accelerated processing was within 1 hour after slaughter on one side while the opposite side was conventionally processed after a 24-hour chilling period at 1.7°C. Yield and dimensional traits were measured and no significant differences were found after further processing was implemented. Feasibility of using accelerated processing stated by the author based on his observations is the apparent decreased cooler space requirements and more rapid product turnover rate.

Accelerated processing of the pork carcass immediately following slaughter into primal and processed cuts, was studied by Mandigo et al. (1978) under commercial packing house conditions using 225 market weight hog carcasses. There was a random selection of carcasses from the slaughter operation and one side was assigned to accelerated and the opposite side to conventional processing. Accelerated was processed into primal cuts within 1 hour of slaughter and the conventional was chilled for 24 hours before processing. After chilling and tempering, no significant differences were found in yields between the two processing methods. The author noted minor variation in cutting techniques between the accelerated and conventional processing methods; also he

suggested that redirected quality control standards and experience may reduce this variation.

Electrical Stimulation

Considerable attention to post-mortem electrical stimulation has been focused as a possibility for improving muscle tenderness. Lopez and Herbert (1975) discovered, through the writings of Benjamin Franklin, that the concept of electrical shock to improve tenderness was not new. Franklin had used electricity to kill turkeys and reported a pleasant side effect of improved tenderness.

This practical application of electricity to improve the tenderness in meat was patented by Harsham and Deatherage (1951). The authors indicated the latent energy stored within the muscle was released by electrical irritation and rendered it more susceptible to enzymatic digestion which produced a more tender product. A demonstration of accelerated rate of pH decline in electrically stimulated muscle was reported by the authors.

Chicken muscle electrically stimulated to exhaustion was found to have a faster rate of pH decline and accelerated post-mortem disappearance of ATP, which was reported by deFremery and Pool (1960). Shear values of the stimulated muscles were higher than those of the unstimulated muscles.

Karpatkin et al. (1964) studied the effect of electrical irritation on the rate of glycolysis in frog sartorius muscle and the rate of glycolysis was measured by lactate formation. Formation increased with the number of shocks per minute when parameters of 15 volts and two milliseconds duration were used. Rate of pH decline in muscles of

stimulated pigs, according to Hallund and Bendall (1965), increased. Forrest et al. (1966) and Forrest and Briskey (1967) indicated that muscles from pigs which exhibited a slow rate of post-mortem glycolysis responded more to electrical stimulation than those with an intermediate rate.

Electrical stimulation data reported by Carse (1973) indicated that a brief period of electrical stimulation of freshly slaughtered lamb carcasses using 250 volts per pulse tended to increase subsequent rates of post-mortem glycolysis and hasten rigor mortis onset. Electrical parameters used were 12 millisecond duration at 250 volts applied at a rate of 3 per second. Comparison made by the author showed lower shear force values of muscle from stimulated carcasses frozen at five hours post-mortem compared to carcasses frozen at 16 hours post-mortem. The author also reported that voltage was related to the degree or rate of post-mortem glycolysis.

Chrystall and Hagyard (1975) investigated the use of electrical stimulation as a process for acceleration of conditioning and increasing tenderness in lamb carcasses. The success of trials involving stimulation, either pre- or post-dressing, were variable. Pre-dressing stimulation, although more difficult, resulted in better tenderness. Stimulation of the dressed carcass was effective if freezing the carcass was delayed. Chalcroft and Chrystall (1975) studied current flow distribution patterns by hooking one leg or both legs to one electrode and the opposite to the neck. Using tenderness for the measurement of current flow, they found that there was a difference in tenderness between the legs if only hooked to one leg; but when attached to both legs there was no difference. Lamb conditioning time can be reduced

from 16 hours to about one hour by using post-mortem electrical stimulation reported by Devine et al. (1975); also the authors reported that there were advantages in reduced handling and spoilage, and in saving both time and space. Chrystall and Hagyard (1975) compared post-mortem glycolysis and shear force values of frozen lambs. They used a high voltage stimulation (3600 volts) and took the measurements at 60 minutes post-mortem. The authors reported an accelerated rate of glycolysis for the stimulated sides and the shear force values of the stimulated were approximately one-half of the unstimulated values. Davey et al. (1976) reported on a similar study using high voltage (3600 volts) on beef carcasses and found the time for rigor mortis was reduced from 24 hours to about 5 hours post-mortem. He reported an increased tenderness in the Longissimus Dorsi muscle and a faster pH drop which indicated a faster rate of glycolysis.

Bendall et al. (1976) electrically stimulated beef carcasses shortly after slaughter at varying voltages, pulse frequency, and duration, with the aim of accelerating the fall of pH, destruction of ATP, and onset of rigor in the muscles, so that the meat could be chilled rapidly after slaughter without danger of cold shortening. The results showed that voltages of about 700, with the current applied for at least two minutes, with a frequency of 25 Hz applied immediately after slaughter or in a dressed state 50-60 minutes later was very effective in rapidly lowering the ATP level and pH of the major muscles. Fall in pH from 6.3 to 5.7 in the stimulated sides was more than four-fifths faster in time than in the unstimulated sides. Muscles of stimulated carcasses showed no deleterious effects of stimulation. Drip loss observed from the hind-limb jointed six days after slaughter was not

significantly greater than that from unstimulated carcasses.

Gilbert and Davey (1976) and Gilbert et al. (1976) studied the effects of high voltage (3600 volts) electrical stimulation immediately after carcass dressing with hot boning and they reported an improvement of tenderness and rigor developed in 5 hours and the ultimate pH of the meat being reached in that time.

McCollum (1977) compared three periods of electrical stimulation--30, 15, and 3 minutes--to an unstimulated control side on beef carcasses. The author measured pH decline and observed a quick pH drop in the stimulated sides which would indicate an increased rate of glycolysis and pH decline difference between the 3 minute stimulation and the 30 minute was not significant. Pierce (1977) conducted two experiments involving electrical stimulation of twelve Hereford steer and heifer carcasses with six of these being used in each of the two experiments. Treatment involved in experiment one was at 1 hr. post-mortem 30 minutes of electrical stimulation with all muscles excised at four hours post-mortem. Experiment two was treatment at 30 minutes post-mortem 15 minutes of electrical stimulation with all muscles excised at two hours post-mortem. Results of the experiment were that the stimulated muscles evaluated were an average of 1.12 kilograms more tender than the controls and the taste panel evaluation supported the findings.

Tang (1977) studied the myoglobin derivatives of bovine muscles from carcasses that were treated with post-mortem electrical stimulation. Visual appraisal of the stimulated samples found them to be bright red in color, while the control samples were dark purplish red. Total pigment and total myoglobin concentrations were not affected by

stimulation.

ATP depletion and muscle microstructure disruption was reported by Will (1978) on post-mortem electrical stimulation on four bovine muscles. ATP depletion was significantly lower at 1-8 hours post-mortem and no statistical difference between control and stimulated sarcomere lenghts were shown to exist and there was some microstructure damage due to the severe contraction involved.

Savell et al. (1978) studied the effect of post-mortem electrical stimulation and cooler aging on fifty light-weight heifers. Parameters studied were the effects on marbling, lean color, incidence of "heat-ring," and shear force. Results reported by the authors were that lean color was significantly improved, incidence of "heat-ring" was reduced, one group resulted in higher marbling scores, and shear force was significantly reduced.

Physical disruption of the muscle microstructure reported by Will (1978) was supported by Savell et al. (1978) when they electrically stimulated the right side of five steers and took light and electron micrographs. Savell et al. (1978) reported the structures of control and stimulated samples differed greatly in the light micrographs and electrically stimulated samples displayed contracture bands in certain areas and slightly stretched sacromeres in other areas. In the electron micrographs definite structural differences were apparent between electrically stimulated samples and control samples. The electrically stimulated samples showed less well defined I-bands and Z-lines through the contracture bands and sarcomeres on either side of the contracture bands seemed to be stretched or broken. Sacromere lengths were not significantly different between the treated and control samples.

Post-mortem electrical stimulation of pork studied by Westervelt and Stouffer (1978) on 32 Yorkshire hogs of approximately 95 kilograms live weight were assigned to one of four treatment groups, either normal slaughter, spinal cord severed after exsanguination, electrical stimulation of whole intact carcasses after exsanguination, or electrical stimulation of right side of eviscerated and split carcass with the left side having no stimulation. Longissimus muscle quality was measured by 24 hour post-mortem pH, visual color score, Gardner color measurements with white and red standards, expressible juice ratio, Warner-Bratzler shear force, sarcomere length (laser and microscope) and fiber diameter. Results of this study were that no significant differences between carcass sides or among treatments were found; also the visual and Gardner color measurements were highly correlated and the treatments were not effective in altering the quality characteristics.

Smith et al. (1979) studied the effects of electrically stimulated beef carcasses with hide-on or hide-off on color, flavor, juiciness, tenderness or overall palatability of the loin. Hide-on improved color of the subcutaneous fat, but the other parameters were not improved significantly more than the hide-off stimulation treatment. Electrical stimulation can be used to enhance the tenderness of loin steaks from calf carcasses, irrespective of dressing style (hide-on versus hide-off).

Muscle Color

Color of pork muscle has little effect on its nutritional properties. Ease with which it is merchandized is affected by its general

appearance which is created by the degree of pigmentation and pigment variation among muscles. The most obvious visual alteration in post-mortem muscle is color change. In normal porcine muscle the color is converted from a relatively dark red to a lighter gray-pink (Cassen, 1966). Lawrie (1950) suggested that muscles with the same pigment content can vary in appearance depending upon the muscle tissue pH. He suggested that myoglobin appeared darker at a high pH than at a low pH, and that muscle consistency and pH are important determinates in muscle color formation. Hamm (1953) reported that with a low pH the water would be released, the structure would become more dense, and the light rays would be reflected from the surface areas and give the muscles a pale appearance. In addition, he suggested that the light rays penetrated deeply into the fresh hydrated muscle, thus giving the muscle a dark appearance. Some authors feel meat color is due to the interaction between pigment concentration and the transparency of the meat fibers. Also, some researchers reported that poor transparency is normally associated with pale color, and that a high pigment concentration may compensate for poor transparency resulting in apparent greater redness in the meat.

It is generally accepted that muscle pigment concentrations vary from animal to animal and that contiguous muscles of pork frequently exhibit pronounced variation in color. These color differences are partially due to the muscle location and function. Dark colored muscles contain a higher myoglobin concentration than the lighter muscles (Briskey et al., 1960). Lawrie (1950) concluded that the principal factor contributing to myoglobin increase in muscles was the demand for oxygen as the result of increased activity, either by growth or

exercise. Also, he stated that active pigs possess darker muscles with greater myoglobin concentrations than inactive pigs. This suggested one explanation for the wide variation in myoglobin concentration within muscle classes and also among individual muscles. In addition, he found that myoglobin content increased with age. In later work, Lawrie et al. (1963) compared myoglobin concentrations of muscles from the ham, loin, and shoulder regions of pigs slaughtered on a weight basis. The analysis indicated that the myoglobin content increased with body weight.

Reflectance as a measure of pork and beef muscle tissue color reported by Ockerman and Cahill (1969) was determined on seven pork and seven beef Longissimus Dorsi muscles. Beef and pork tissues were visually evaluated by a trained panel and then subjected to a reflectance measurement. Reflectance was observed to be a rapid, objective method of measuring muscle color and results were in good agreement between visual panel scores and predicted values.

Several methods of evaluating the desirability of meat color have been investigated, and the tristimulus colorimetry method is one of many used today. Product color characteristics (hue, chroma, and value) can be evaluated by using the reflectance readings from the Photovolt Reflection Meter (with tristimulus filters). Reflectance measurements were obtained and were converted to Commission Internationale de l'Eclairage (C.I.E.) tristimulus values, X, Y, and Z. The Hunter color system of color coordinates is in more common usage for meat color analysis. The color dimensions (L, a, and b) give objective values with which to discern color differences.

Rigor Mortis

Upon death of an animal three major changes interrelated to the conversion of muscle to meat take place and these are loss of ATP, oxygen depletion and a drop in pH.

Living tissue has an environment in which glucose is continually transported into the cells providing a source of energy. Upon death of the living muscle tissue the aerobic glycolysis converts to anaerobic glycolysis with production of lactic acid and the breakdown of creatine phosphate which served as a mechanism for resynthesis of ATP from ADP. Infante and Davies (1962) observed that the onset of shortening in rigor mortis, after the release of Ca^{++} into the sarcoplasm, could be attributed to cyclic formation and breakage of actin and myosin cross-links which were accompanied by enzymatic hydrolysis of ATP by calcium activated actomyosin ATP-ase and rigor mortis continues to develop until ATP is depleted. After death the ATP-ase activity of the muscle fiber continues to rapidly deplete the ATP. This was true because net ATP production from respiration and glycolysis was inhibited and resynthesis of ATP via creatine phosphate is prohibited and the creatine phosphate levels are reduced. As the ability to produce ATP was altered, the crosslinks which were once able to break and reform no longer have the energy source to perform relaxation and contraction; thus, the muscle becomes inelastic.

Bate-Smith and Bendall (1949) defined rigor mortis as being a delay period in which the modulus of elasticity either does not change at all or increases rapidly to its maximum which may be 10 to 40 times higher than the initial value. The time it takes for resynthesis of

ATP via glycolysis was determined solely by the maximum fall of the pH post-mortem and as long as there was enough ATP resynthesis from the glycolytic cycle the muscle did not pass into rigor mortis. They further stated that an ultimate pH of 5.3 appeared to be a limiting value, beyond which glycolysis was completely inhibited.

In 1951, Bendall suggested that creatine phosphate was the first chemical compound to be broken down during the course of rigor mortis in resting muscles at 37°C and 17°C. ATP depletion did not occur until 70% or more creatine phosphate had disappeared, and as with earlier investigations, ATP was found to diminish relatively quickly, depending upon how fast glycolysis proceeded.

ATP level at which shortening beings depends upon the ultimate pH of the muscle and the rate of decline before onset of rigor mortis. The onset of rigor mortis found by Briskey et al. (1962) was from two minutes to eight hours in porcine muscle. Sayre and Briskey (1963) used a rigorometer devised by the authors to measure the time course of rigor mortis in porcine muscle and rigor in animals tested was completed within five hours after death. Definition of rigor mortis by Marsh (1954) was when all glycolitic processes are completed, about 36 hours. deFremery and Pool (1960) demonstrated the faster the onset of rigor mortis whether measured by glycogen, drop in pH, or breakdown of ATP the less tender will be cooked Pectoralis major muscle in poultry. pH decline in muscle post-mortem has been used by several researchers to follow the time course of rigor mortis and tenderness.

Temperature is related to rate of pH decline (Bate-Smith and Bendall, 1949; Bendall, 1951; Bendall, 1961; deFremery and Pool, 1960; Cassens and Newbold, 1967). Marsh (1954) demonstrated the effect of

temperature in that increasing the temperature from 7°C to 43°C resulted in faster rates of pH decline, but no difference was found in ultimate pH between grades of beef.

Temperature influences the extent and severity of rigor mortis, muscle shortening, and ultimately tenderness. Shortening of beef muscle is much greater at 0-15°C than at higher temperature (20-43°C) reported by Wilson et al. (1960), also one must not forget the accelerated aging to be expected at higher temperatures which could obscure any toughening produced during rigor mortis onset at elevated temperatures. Locker and Haygard (1963) reported that isolated fresh Sternomandibularis muscle developed minimum shortage at 4-19°C and temperatures higher than this range shortening coincided with the onset phase of rigor mortis. Forrest et al. (1969) found the porcine muscle permitted to go into rigor mortis at 2°C was significantly less tender and shortened more than similar samples held at 16°C.

Galloway and Goll (1967) studied shortening and tension of porcine muscle segments immediately post-mortem and again after eight hours post-mortem at four different storage temperatures (2°, 16°, 25° and 37°C). Muscle segments were shown to shorten and or develop tension at all post-mortem storage temperatures; also shortening was reported maximal at 2°C and 37°C and minimal at 16°C with 2°C shortening occurring faster than at all other temperatures.

Development of rigor mortis and consequent shortening affects tenderness of meat and tenderness is probably the one attribute most related to meat quality. It would be desirable to have a product that would be as tender as possible which would mean to minimize or prevent toughening from occurring. Implementation of electrical stimulation

and new chilling methods which allow rigor mortis to develop at a temperature at which post-mortem shortening is at a minimum, thus give a product of maximum tenderness.

CHAPTER III

MATERIALS AND METHODS

Ten Yorkshire hogs ranging in weight from 120 to 95 kg with a mean weight of 105 kg were utilized in this study. Each animal was delivered to the Meat Science abattoir 24 hours prior to slaughter. Following the 24 hour shrinkage period, the live weight of the animal was taken and recorded. Care was exercised in handling the animals to avoid any adverse effect upon post-mortem metabolic reactions, as well as ultimate product quality. Each animal was stunned with a Cervin electrical tool (220 volt), shackled by one leg, raised from the floor, and bled. The time of death was recorded. Remaining portion of the slaughter was according to the procedures consistent with methods and practices currently used in the industry. Also, the carcasses were carefully washed to minimize bacterial contamination. The slaughter and dressing operations proceeded as such that Federal Inspection was given within 30 minutes post-mortem. Carcass was split into sides suspended from a rail via roller and hook through the Achilles tendon. Following inspection of the split carcass, the hot weights of both the right and left sides were recorded. The sides were immediately moved to a 16^{o}C holding room and were randomly assigned to one of two treatments: (1) electrical stimulation or (2) no electrical stimulation (control).

At one hour post-mortem, the side to be stimulated was connected to a pulse generator via two leads. Connection was made by two

springloaded triangular shaped steel clamps with serrated teeth. Lead one was attached to the rear shank; the other lead was attached to the neck region near the third and fourth cervical vertebrae.

The pulse generator delivered a direct current square wave pulse with a frequency of 400 cycles per second and a duration of .5 milliseconds. Voltage was 300 maximum with 1.8 amperes of current, as read from a Hewlett Packard model 120 AR Oscilliscope. Electrical stimulation was initiated at one hour post-mortem and concluded after 90 seconds of stimulation.

Upon termination of stimulation, the leads were removed and the following muscles were removed from both sides: Longissimus Dorsi (LD), Psoas Major (PM), Biceps Femoris (BF), Semitendinosus (ST), and Semimenbranosus (SM). The carcasses were skinned and the excess surface fat removed as soon as the excision of the LD, PM, BF, ST, and SM was completed; any excess fat remaining on the muscle was trimmed off. Each muscle was then labeled and wrapped with a saran film to reduce desiccation. Other components (bone, fat, lean trim, and unutilized muscles) were placed in a 1.1^{o}C cooler and processed at a later time. These components were not utilized in this study. Excision of the muscles from the carcass was completed approximately two hours after initiation.

Sampling for Shear Force, Color Determination, Pressed Fluid, and Organoleptic Evaluation

Each muscle to be tested was cut into 30mm thick chops, by the schematic plan presented in Figure 1. Chops for the press fluid, shear force, color determination, and percent cooking loss were taken

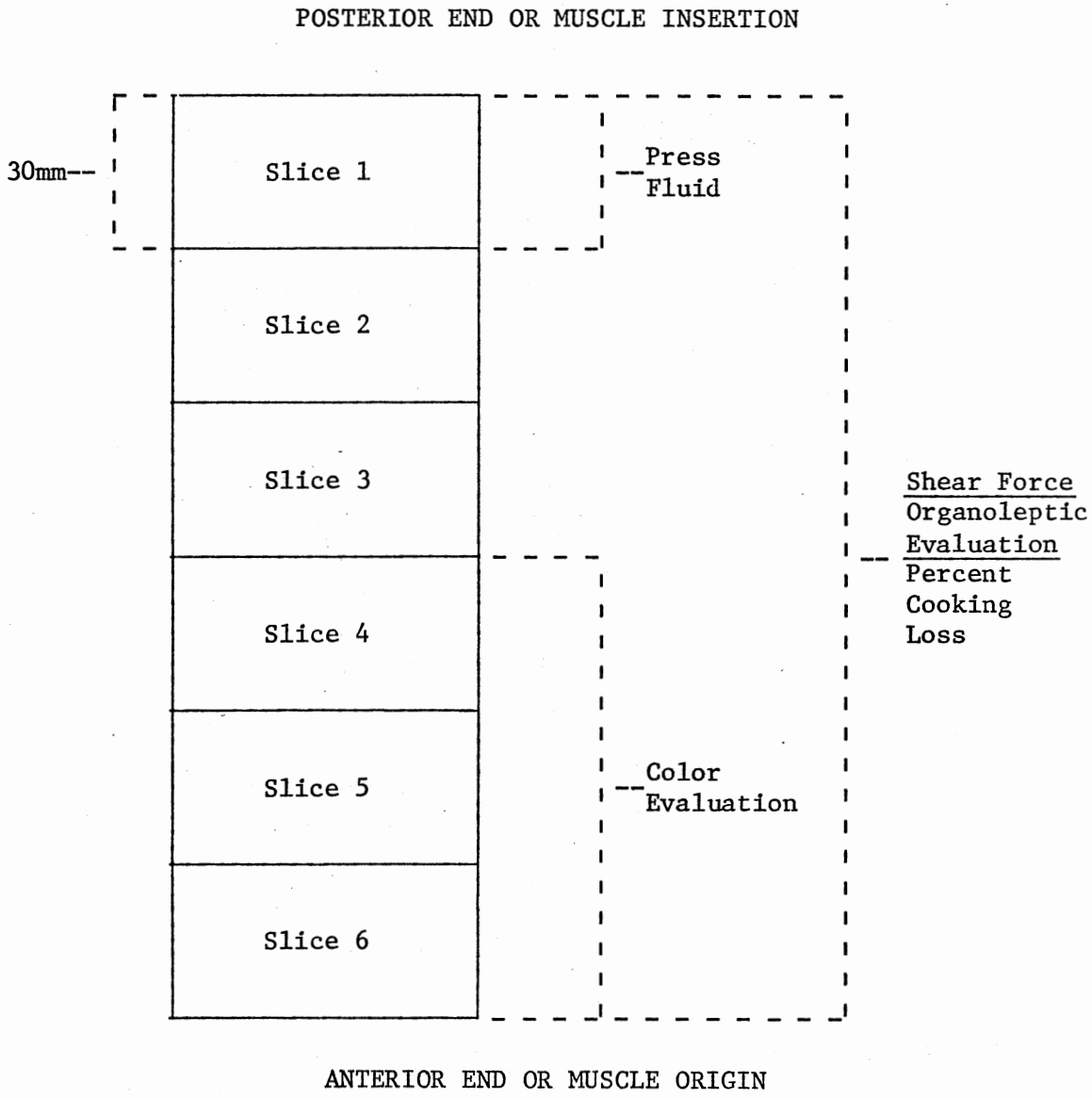

Figure 1. Schedule for Removing Slices for Quality Determinations on Test Muscles

from each of the five muscles. Chops for the organoleptic evaluation were taken only from the LD, BF, and SM muscles. All chops were packaged, labeled, and frozen (-10°C) for analysis at a later date.

Shear Force

Chops from the Longissimus Dorsi, Biceps Femoris, Psoas Major, Semimembranosus, and Semitendinosus muscles were thawed at 1.1°C for 24 hours. Six chops from each of the five test muscles were evaluated; thus 60 chops were analyzed from each of the ten carcasses. Each thawed chop was labeled with a metal clip and tag to identify pig number, side, treatment, and position. Position number 1 would be denoted as the chop nearest the posterior end of the muscle. Each chop was towel dried and weighed. Each group of twelve chops from the same muscle (6 control and 6 stimulated) was placed in an aluminum tray and cooked in a Blodgett convection oven set at 142°C until an internal meat temperature of 73°C was reached. Premium Instrument meat thermometer was inserted into the geometric center of the uncooked chops to record the internal doneness. After being cooked, the chops were removed from the oven, blotted, and allowed to cool at room temperature approximately 15 minutes and chops were then reweighed.

Cooked chops were further cooled for another 45 minutes and then covered with aluminum foil and chilled for 24 hours at 1.1°C to provide adequate firmness to insure uniform cores (Kastner and Henrickson, 1969).

Proceeding from here each chop was taken and sliced into rectangular shaped pieces measuring 19mm (wide) x 14mm (length) x 38mm (thickness) and care was taken to slice all pieces in the same

manner. Also, on each muscle from carcasses 6-10 one 20mm diameter core (Falk, 1974) was taken by a mechanical boring device (Kastner et al., 1973). Each of the above pieces was analyzed for shear force by an Instron Universal Testing Machine (Model 1122) with a Kramer cell shear press head. Settings were chart speed at 200mm per minute, a cell shear press head speed of 200mm per minute, and a full scale load of 200 kilograms on the chart paper, providing a total of 1 to 2 shear force readings per chop.

Color Evaluation

Thirty chops (3 chops from each of the five muscles for each side; Figure 1) were evaluated on the basis of color value. Chops were cooked, then chilled for 24 hours at 1.1°C before readings were taken. A Photovolt Reflection Meter (Model 610) with a 610-Y search unit was used to measure the percent reflectance from the cut surface of the chops. Photovolt Reflection Meter with a green filter in the search unit was adjusted to 100 percent reflectance using a magnesium oxide surface, then a Munsell 5R 5/12 chip was utilized as a standard. Three colored filters (blue, amber, green) were utilized in the color measurement, each filter being related to each of the color parameters. Readings for each parameter were taken after the instrument was standardized with each filter.

Hue, value, and chroma are the dimensions of color: hue being the color (red, purple, etc.), value which is the degree of lightness to darkness (white = 10, black = 0), and chroma the intensity of a particular color (light red, medium red, etc.). Facilitating analysis and reporting data, these coordinates were converted to Hunter L, a, b

color values. For ease of calculation they were first converted to CIE coordinates by these formulas from Mackinney and Little (1962).

$$X = 0.80A + 0.18B$$

$$Y = 1.00G$$

$$Z = 1.18B$$

Hunter L, a, b values can be easily calculated from these values by using another set of equations by Mackinney and Little (1962).

$$L = 100Y^{1/2}$$

$$a = \frac{17.5(1.02X - Y)}{Y^{1/2}}$$

$$b = \frac{70(y - 0.847Z)}{Y^{1/2}}$$

With these values the degree of lightness and darkness can be determined along with yellowness and redness and used to express color differences. No attempt was made to determine the actual meat color.

Pressed Fluid

First three chops from the posterior end of the muscle were used for the determination of pressed fluid. One sample was cut from each chop and a transverse section of 500 milligrams was extracted from the center of each chop. Muscle tissue section was then placed on the center of Whatman No. 1 qualitative filter paper that was 12.5 centimeters in diameter. Filter paper and sample were placed between two clean plexiglass plates and pressed one minute at 4536 kilograms load on the ram of a Carver Laboratory Press. Care was exercised to avoid moisture evaporation from the samples prior to pressing. Prior to use, the filter paper was held in a desiccator jar which contained a small amount of saturated potassium chloride. This insured that the filter

paper was of a constant humidity (Carr, 1970). Once the samples were pressed, the resulting meat ring was traced with a pencil and the pressed sample was discarded. Filter papers containing the traced meat ring and the moisture ring were dried for 24 hours at room temperature. After the papers were sufficiently dry, each area (meat ring and moisture ring area) was measured twice using a Compensating Polar Planimeter. Measured areas were used to calculate a dimensionless ratio which represented the pressed fluid in that sample (Sayre et al., 1963). Thus, the larger the ratio, the more pressed fluid per unit area of sample.

Organoleptic Evaluation

(Tenderness Panel)

Longissimus Dorsi, Semimenbranosus, and Biceps Femoris muscles were appraised by a trained tenderness panel. Panel consisted of six members, both men and women, of different ages selected from the employees of the Meat Science Laboratory. Panelists participated in five training sessions to familiarize them with test procedures, and they were given a wide variety of differing degrees of meat tenderness to test their ability to discriminate.

Duo-trio test (Kramer and Twigg, 1970; Amerine et al., 1965) was used to determine whether differences in tenderness existed between treatments. Test was organized such that one of the samples served as the reference and the remaining two samples were unknown. Each panelist was asked to choose which of the unknowns best matched the reference sample. Each panelist received the corresponding chop in the same position (e.g., chop 1 evaluated by panelist 1). All chops of

each muscle from both treatments were evaluated at a given setting. A coin toss was made to determine which treatment (stimulated or control) would serve as the pair (reference and corresponding unknown) and which would be designated as the single (odd) sample. Individual muscle system chops were then cooked on a rack in aluminum foil tray in a pre-heated convection oven set at 142°C until an internal temperature of 73°C was reached. Upon attaining this internal temperature, the chops were removed from the oven, blotted and cooled for 15 minutes. A 1.27cm diameter boring device was used to remove 2 cores from each chop. One core was used for the pair samples and one core for the single sample. Chops were carefully oriented so that the cores were removed from the same position up and down the muscle for both the pair and single sample given a panelist. In the case of the single chop, each core was removed from a point midway between the position of the paired cores sampled on the corresponding chop. Each core was placed in a No. 39 3/4 oz. paper souffle cup which fit into a wooden tray (Figure 2). As may be noted three symbols were imprinted on the tray: $, &, !. The dollar sign always served as the reference, whereas the ampersand the exclamation point always were unknown. A coin toss was used to determine which of the two symbols representing the unknown sample would serve as the second member of the pair, matching the reference ($) sample for each muscle evaluated. Randomization as discussed was accomplished before each test session and recorded. After the sample vials were placed in the tray, they were covered with aluminum foil and placed into a warm electric oven and held at 50°C until evaluated. The oven was used to insure that the samples in each tray were at a uniform temperature when they were presented to the

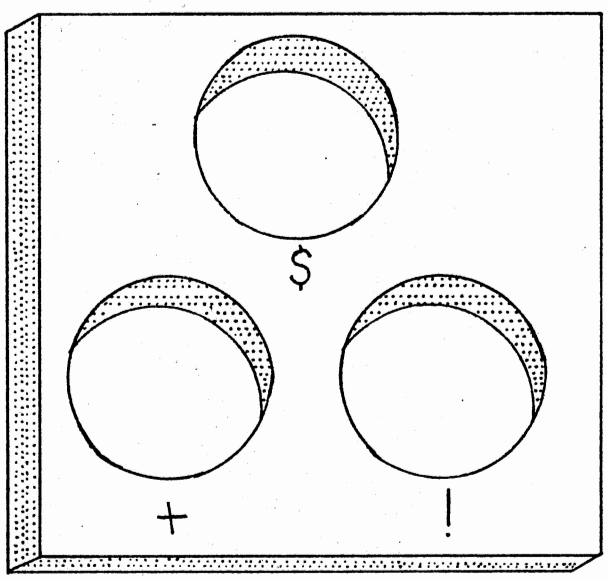

Figure 2. Sample Tray Used in the Duo-Trio Analysis

panelists. Scoring by the panel members was accomplished within 15 minutes after the samples were prepared.

Upon receiving a tray with the three samples, each judge was asked to perform the duo-trio test (see Figure 3). Judges were given sufficient privacy so that independent results were obtained. Care was taken to assure that the evaluation room was dimly illuminated with red light to avoid identification of the samples because of color differences. To eliminate odors from the preparation room, a positive air pressure system was utilized.

Duo-trio panel responses were evaluated by means of Kramer and Twigg (1970) Table 85, such that 38 correct responses out of 60 were required for the attaining of significance at the 5% level.

Percentage Cooking Loss

Pre- and post-cooked weights were taken on each of the chops from the taste panel measurements, as was previously discussed, in order to compare the difference in percentage cooking loss between the stimulated and control. The formula for calculating percentage cooking loss was:

$$\frac{A - B}{A} \times 100 = \text{Percentage Cooking Loss}$$

A = Raw Chop Weight

B = Cooked Chop Weight

Duo-Trio Test

Product _____ Name _____

Date _____

Two of the three samples are similar.

Please circle the two similar samples:

$

& !

Figure 3. Taste Panel Evaluation Sheet

Statistical Design and Analysis

SAS computer programming system (Barr and Goodnight, 1972) was used to analyze all data presented in this study. Data for each muscle were analyzed as a split-plot in which the main plots were two treatments; subplots were positions in each treatment. The mainplot was set up as a randomized block design in which the hog was the block. Two treatments were control and a 90-second electrical stimulation and the side that received electrical stimulation for each hog was decided by toss of a coin. Organoleptic data were evaluated by using the ranking procedure described by Kramer and Twigg (1970). Appendix contains means of the mainplot and subplot.

CHAPTER IV

RESULTS AND DISCUSSION

Color

Degree of muscle lightness or darkness (L value), redness (a value), and yellowness (b value) of the cooked meat surface was determined to see if any color difference exists between the electrically stimulated and control carcasses (no stimulation). In general, the higher the lightness (L value) the lighter the color of the cooked surface of the meat.

Data presented in Table I and Figures 4 and 7 show that lightness values were significantly higher ($P < .05$) for the electrically stimulated Semitendinosus while the remaining four muscles showed no difference ($P > .05$) in the mainplot. Data presented in the Appendix (Tables IX, X, XI) show only the Longissimus Dorsi to have significant position by treatment interaction ($P < .05$).

Redness (a value) (Table II and Figures 5 and 8) was significantly higher ($P < .05$) for the Semimembranosus from the electrically stimulated side as compared to that from the control side. However, the remaining four muscles had no significant difference between the control and treated muscles ($P > .05$) in the main plot. Data presented in the Appendix (Tables IX, X, XI) show no significant ($P > .05$) position by treatment interaction for any of the muscles tested.

TABLE I

LIGHTNESS VALUES (L) OF PORCINE MUSCLE AS INFLUENCED BY ELECTRICAL CURRENT

Muscle	NOB[4]	"L" Values[1] Control	Stimulated	EMS[2]	OSL[3]
Biceps Femoris	30	82.45	81.51	50.42	0.62
Longissimus Dorsi	30	90.19	90.22	5.57	0.96
Psoas Major	30	77.43	77.92	14.46	0.63
Semimembranosus	30	81.68	80.96	31.82	0.64
Semitendinosus	30	78.38	82.49*	48.64	0.05

* = ($P < .05$).

[1]Nondescriptive Units--which range from 0-199 (0=Black, 100=White).

[2]Error Mean Square = Pig^{X} Treatment, D.F. = 9.

[3]Observed Significance Level.

[4]Number of Observations.

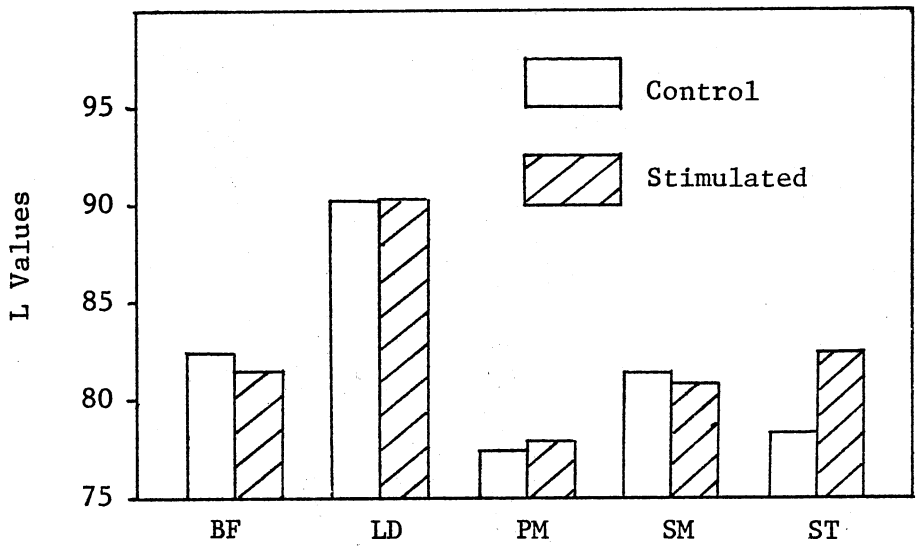

Figure 4. Lightness Values (L) of Porcine Muscle as Influenced by Electrical Current

TABLE II

REDNESS VALUES (a) OF PORCINE MUSCLE AS INFLUENCED BY ELECTRICAL CURRENT

Muscle	NOB[4]	"a" Values[1] Control	Stimulated	EMS[2]	OSL[3]
Biceps Femoris	30	9.41	9.35	39.72	0.97
Longissimus Dorsi	30	11.79	8.31	98.61	0.21
Psoas Major	30	16.05	15.16	63.04	0.67
Semimembranosus	30	10.26	13.41*	23.19	0.03
Semitendinosus	30	13.32*	11.62	102.26	0.53

* = ($P < .05$).

[1]Nondescriptive Units--higher the number denotes more redness.

[2]Error Mean Square = Pig^{X} Treatment, D.F. = 9.

[3]Observed Significance Level.

[4]Number of Observations.

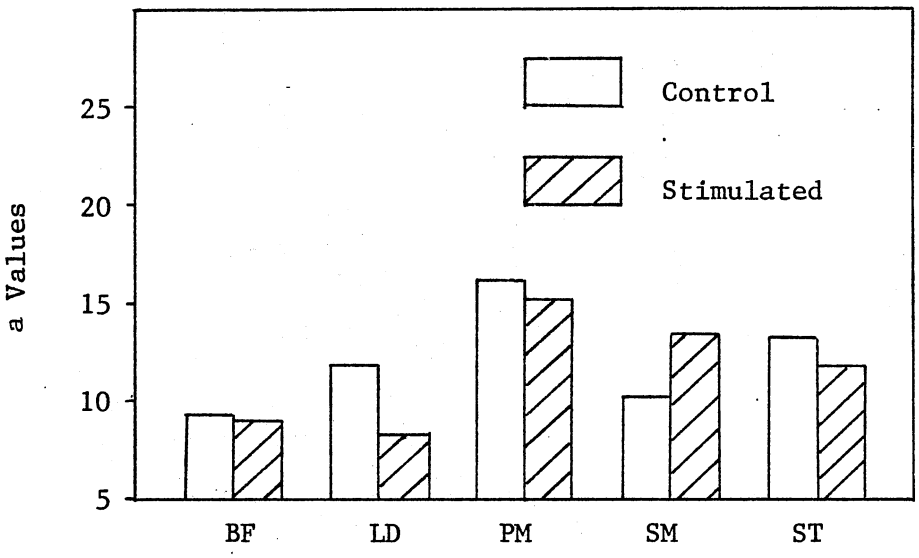

Figure 5. Redness Values (a) of Porcine Muscle as Influenced by Electrical Current

Yellowness (b value) (Table III and Figures 6 and 9) were significantly higher ($P < .05$) for the Semimembranosus from the control side (no stimulation) than from electrically stimulated side, while yellowness of the remaining four muscles had no significant difference between the control and treated muscles ($P > .05$) in the main plot. Data presented in the Appendix (Tables IX, X, XI) show only the Semitendinosus to have significant position by treatment interaction ($P < .05$). Even though the position by treatment interaction is statistically significant the practical significance is minimal.

Forrest and Briskey (1967) indicated a slight visual color difference in electrically stimulated raw Longissimus pork muscle from Yorkshires, resulting in paler color. Recently, Westervelt and Stouffer (1978) reported that electrically stimulated Longissimus muscle has slightly lower visual score. However, they could not detect any significant differences between electrically stimulated and control (no stimulation) as determined by Gardner color scores. According to Tang (1977) electrically stimulated bovine muscles contain a higher oxymyoglobin content reflecting a brighter colored muscle tissue. This difference may disappear after cooking the muscle.

Pressed Fluid Ratios

Pressed fluid ratios may be viewed using two criteria. The larger the ratio the less the water-binding capacity of the meat (Sayre et al., 1963) or the larger the ratio the more juicy the product (Cagle, 1969). However, a juicy raw product may be the exact opposite once it is cooked.

TABLE III

YELLOWNESS VALUES (b) OF PORCINE MUSCLE AS INFLUENCED BY ELECTRICAL CURRENT

Muscle	NOB[4]	"b" Values[1] Control	Stimulated	EMS[2]	OSL[3]
Biceps Femoris	30	17.56	17.14	16.27	0.69
Longissimus Dorsi	30	15.28	15.80	7.74	0.51
Psoas Major	30	15.27	15.40	13.36	0.89
Semimembranosus	30	16.05*	13.66	4.82	0.01
Semitendinosus	30	14.99	17.21	35.40	0.18

* = ($P < .05$).

[1]Nondescriptive Units--Higher number denotes more yellowness.

[2]Error Mean Square = Pig^{X} Treatment, D.F. = 9.

[3]Observed Significance Level.

[4]Number of Observations.

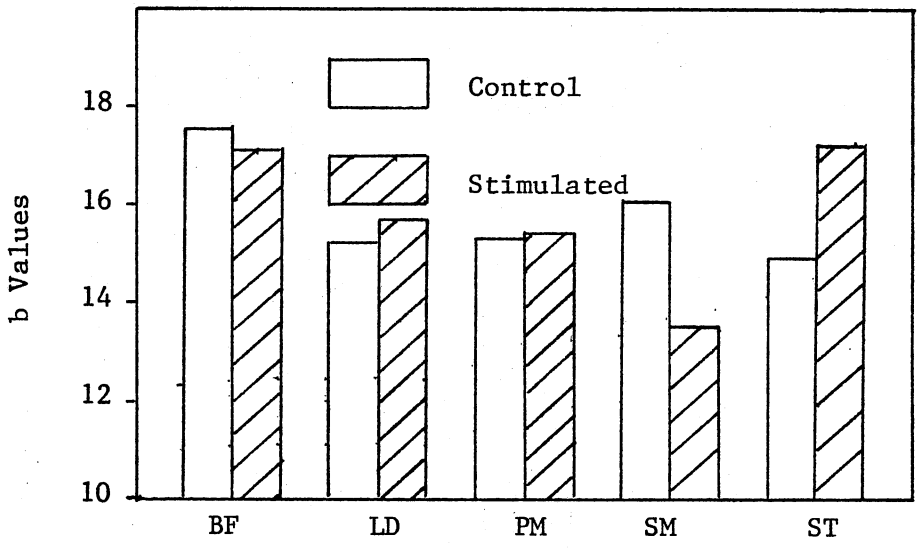

Figure 6. Yellowness Values (b) of Porcine Muscle as Influenced by Electrical Current

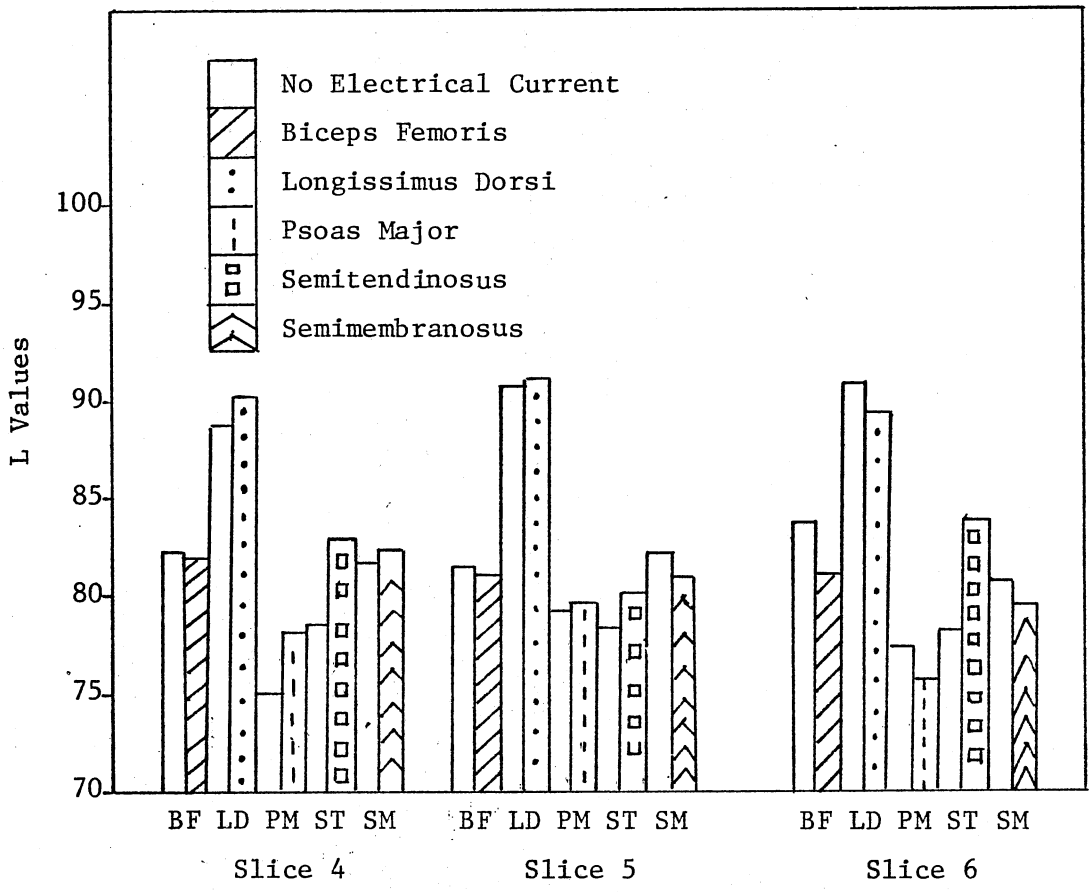

Figure 7. Composite Lightness Values (L) for Porcine Muscle as Influenced by Electrical Current

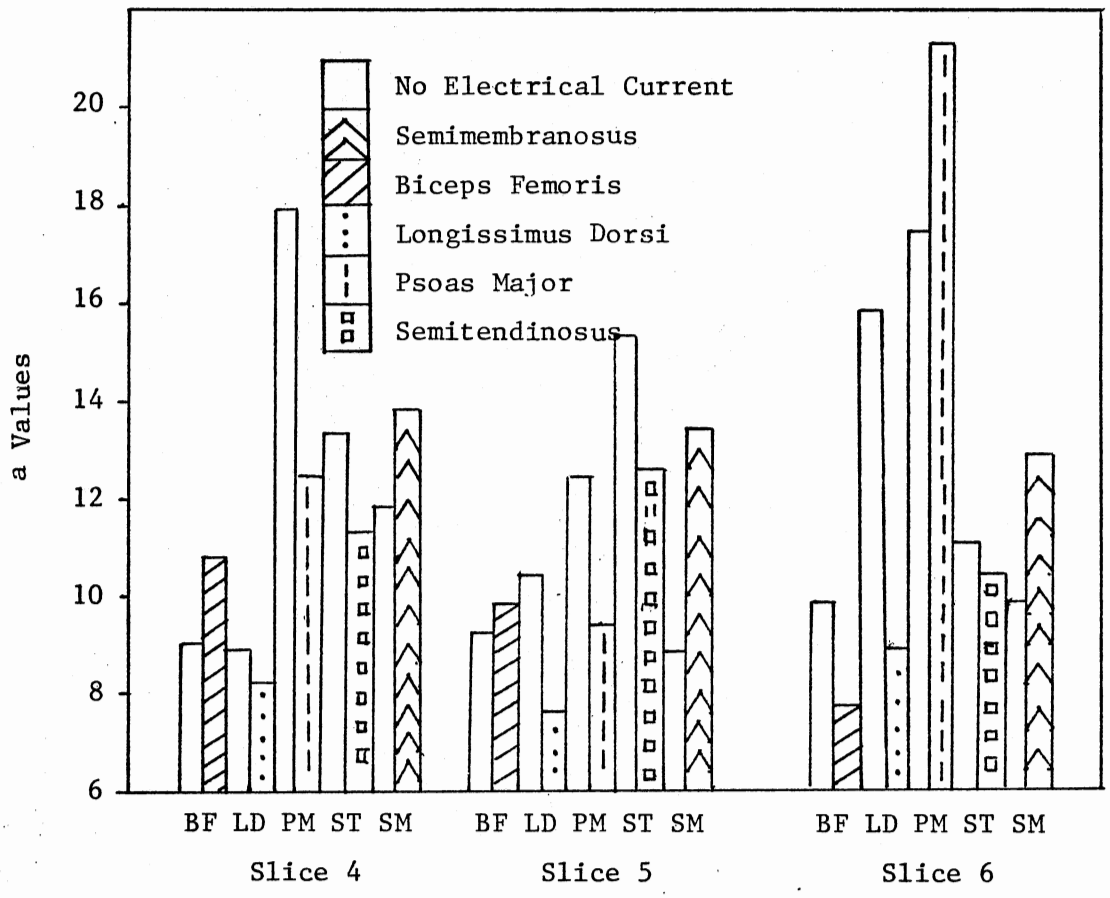

Figure 8. Composite Redness Values (a) for Porcine Muscles as Influenced by Electrical Current

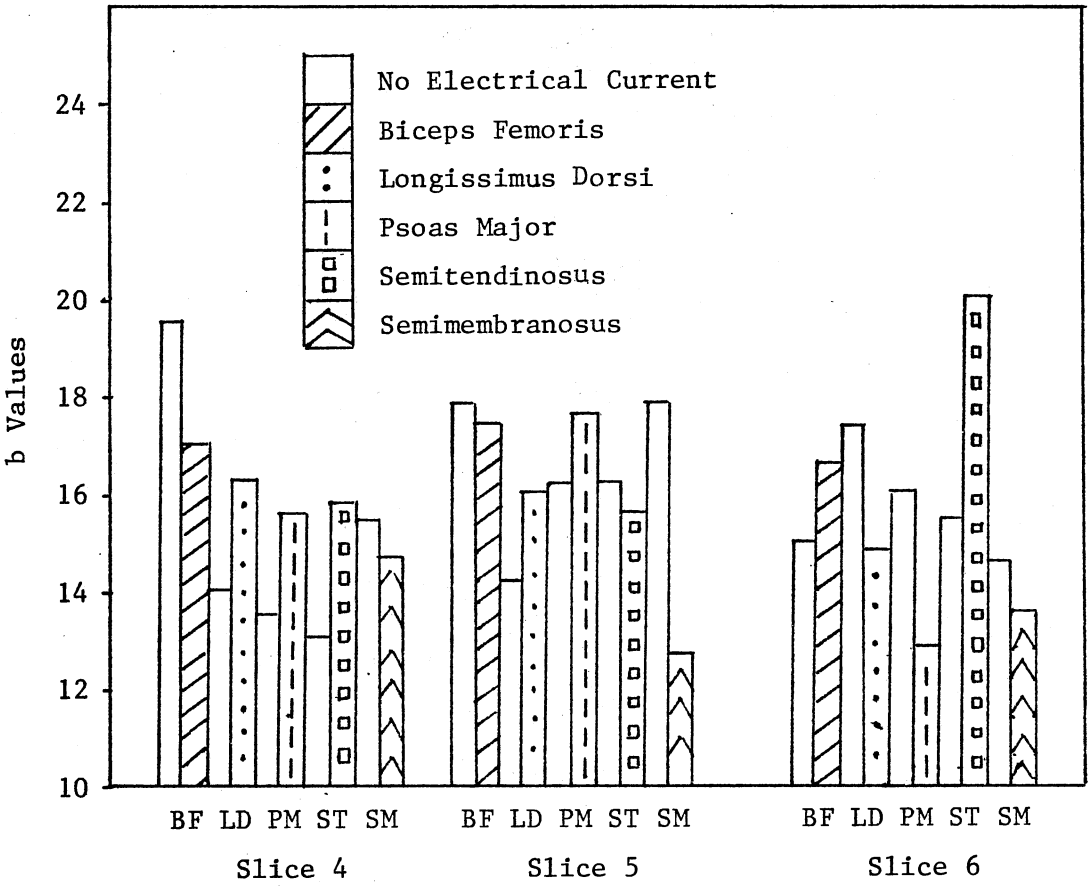

Figure 9. Composite Yellowness Values (b) for Porcine Muscles as Influenced by Electrical Current

Electrical stimulation can affect the rate of pH decline in bovine muscle. Rate of pH drop in post-mortem muscle affects the water-binding capacity of meat (Lawrie, 1966), and ultimately the amount of pressed fluid. Westervelt and Stouffer (1978) reported no difference in water-holding capacity of pH for electrically stimulated porcine Longissimus Dorsi muscle.

Evaluation of pork muscle differences are shown in Table IV and Figure 10. Data presented showed no statistical significance ($P > .05$) in the main plot for the five muscles evaluated. Statistical analysis of Appendix (Table XII) data reveals some significant position by treatment interaction for the Biceps Femoris and Psoas Major but yet this is of little practical significance considering its occurrence. Since there were no major treatment differences in water-holding capacity for the five muscles, one may conclude that the slower the pH descends the less the protein denaturation, thus the greater the water-binding capacity. It seems that electrical stimulation did not accelerate post-mortem pH decline in the muscles studied which would support the findings of Westervelt and Stouffer (1978).

Shear Force Evaluation

Shear force values, as measured by the Universal Instron (Model 1122) testing machine with a Kramer Shear Press Cell found that there were no significant differences in the main plot ($P > .05$) between the stimulated and control samples from the Biceps Femoris, Longissimus Dorsi, Psoas Major, Semimembranosus, and Semitendinosus muscles (Tables V, VI and Figures 11, 12). Evaluation of tenderness in Table VI and Figure 12 is the number of kilograms of shear force required to shear

TABLE IV

MEAN PRESS FLUID RATIO OF PORCINE MUSCLE
AS INFLUENCED BY ELECTRICAL CURRENT

Muscle	NOB[4]	Press Fluid[1] Control	Stimulated	EMS[2]	OSL[3]
Biceps Femoris	30	4.61	4.65	1.90	0.29
Longissimus Dorsi	30	4.57	4.60	1.48	0.54
Psoas Major	30	4.96	4.89	10.97	0.59
Semimembranosus	30	4.64	4.62	12.45	0.79
Semitendinosus	30	4.75	4.85	6.71	0.16

* = ($P < .05$).

[1]Measurement in square inches and higher the value less water holding capacity.

[2]Error Mean Square = Pig^{X} Treatment, D.F. = 9.

[3]Observed Significance Level.

[4]Number of Observations.

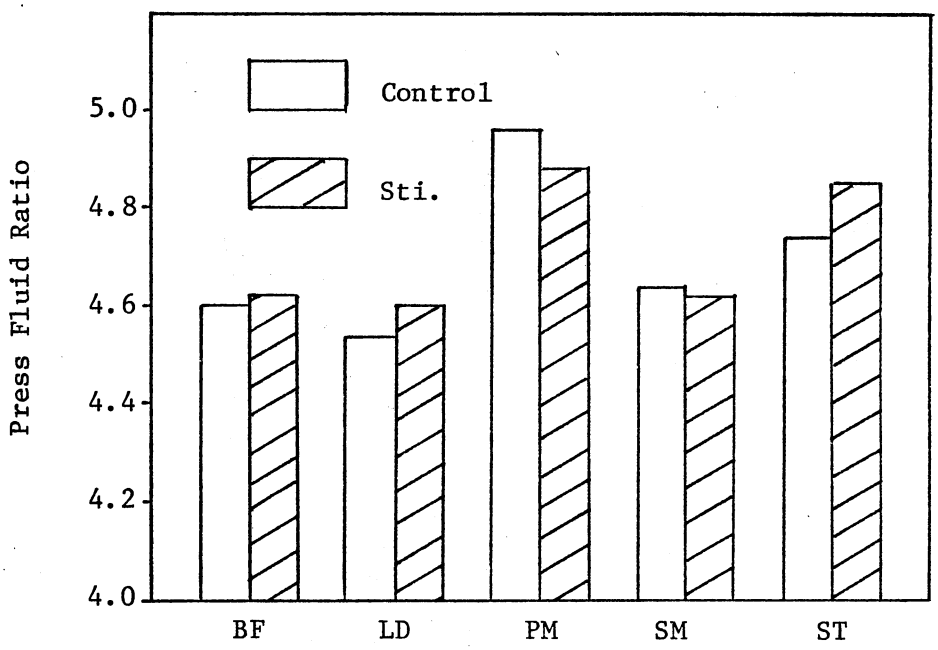

Figure 10. Mean Press Fluid Ratio of Porcine Muscle as Influenced by Electrical Current

TABLE V

MEAN SHEAR FORCE VALUES OF PORCINE MUSCLE AS INFLUENCED BY ELECTRICAL CURRENT

Muscle	NOB[4]	Shear Force (kg)[1] Control	Stimulated	EMS[2]	OSL[3]
Biceps Femoris	60	51.99	51.73	72.26	0.86
Longissimus Dorsi	60	41.98	42.26	43.24	0.81
Psoas Major	60	55.48	56.24	334.59	0.82
Semimembranosus	60	46.59	48.53	59.27	0.19
Semitendinosus	60	49.13	49.18	55.23	0.97

* = ($P < .05$).

[1]Denotes peak force over time in kg/sq. inch and higher values less tenderness.

[2]Error mean square = Pig^{X} treatment, D.F. = 9.

[3]Observed Significance Level.

[4]Number of Observations.

TABLE VI

MEAN SHEAR FORCE VALUES OF PORCINE MUSCLES
AS INFLUENCED BY ELECTRICAL CURRENT

Muscle	NOB[4]	Shear Force (kg)[1] Control	Stimulated	EMS[2]	OSL[3]
Biceps Femoris	60	8.95	9.21	1.34	0.25
Longissimus Dorsi	60	7.55	7.01	8.47	0.33
Psoas Major	60	6.17	6.58	1.28	0.07
Semimembranosus	60	8.58	9.19	9.65	0.32
Semitendinosus	60	6.41	6.24	2.63	0.59

* = ($P < .05$).

[1]Denotes peak force per gram of sample and higher values less tenderness.

[2]Error Mean Square = Pig^X treatment, D.F. = 9.

[3]Observed Significance Level.

[4]Number of Observations.

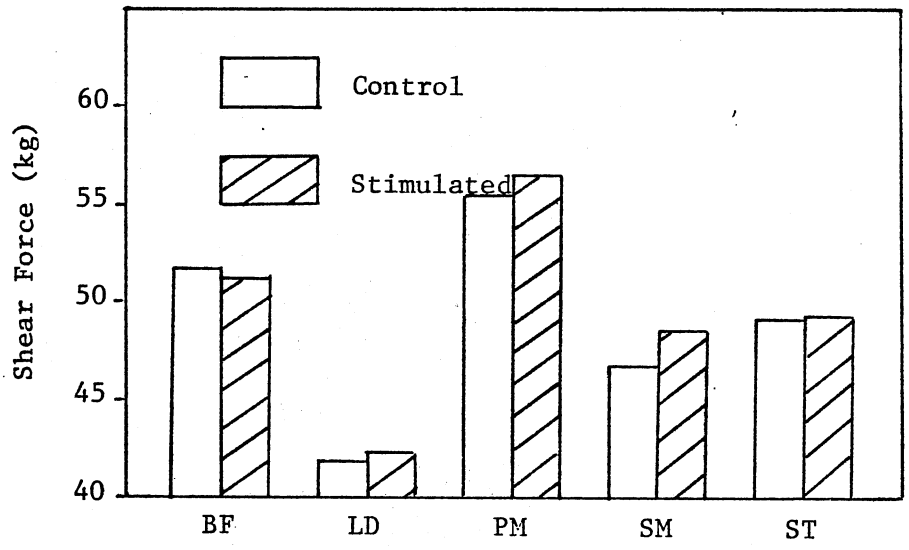

Figure 11. Mean Shear Force Values of Porcine Muscles as Influenced by Electrical Current

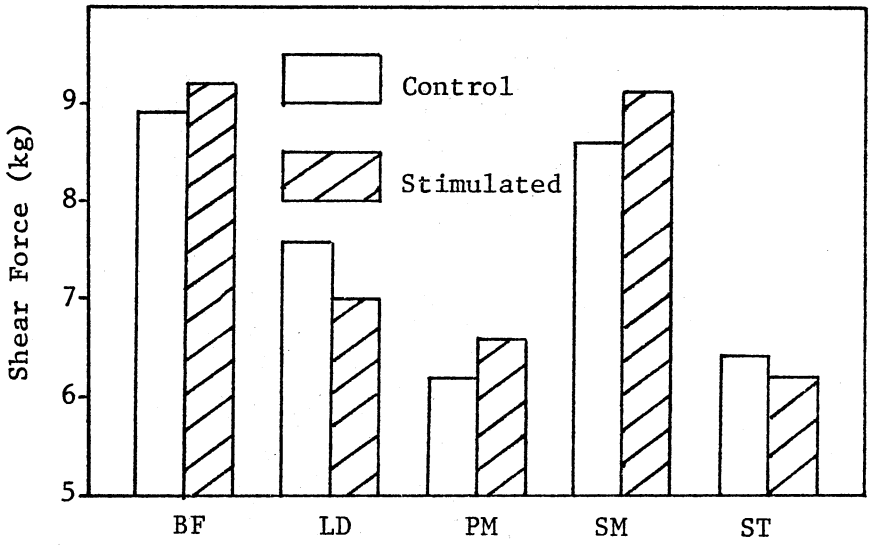

Figure 12. Mean Shear Force Values of Porcine Muscles as Influenced by Electrical Current

one gram of sample being tested. The results showed no significant difference for any of the five muscles tested. The other evaluation was total force and this total force was measured by squared inches charted on graph paper during the shearing process. Evaluation of the data in Table V and Figure 11 shows no statistical significance ($P > .05$) between the treatments for any of the five muscles evaluated. Appendix (Tables XIII, XIV, XV) data reveal some position by treatment interaction which is statistically significant ($P < .05$) in the Semitendinosus, Psoas Major and Biceps Femoris which indicates variations in connective tissue within the muscle. Practical significance of this considering normal variations is very minimal. Table V and Figure 11 show the higher the value, the higher the number of chews it would require to become satisfactory to consume. Longissimus Dorsi, Biceps Femoris, Semimembranosus, and Semitendinosus were as should be expected, but the Psoas Major seemed to be high for both the control and treated samples.

Electrical stimulation did not improve the tenderness of the five muscles, as had previously been shown to occur in beef and lamb carcasses at different voltages and stimulation periods (Cross, 1978). The unexplained mechanism of response of porcine muscle to electrical stimulation may be similar to the cold-shortening characteristics of pork muscle which are only a tenth of those observed in the bovine and ovine species (Marsh et al., 1972; Westervelt and Stouffer, 1978). Another reason suggested by the author is all research that was evaluated was done with hide on the carcass. In beef it is shown that hide on electrical stimulation is not as effective as hide off. If it is assumed that hide and the other components of the carcass had approximately the same electrical resistance then the current would transmit through the hide where its effect would be limited on the muscle.

Percentage Cooking Loss

Percentage cooking loss was evaluated to determine if electrical stimulation would affect this factor. Since hot boning would not cause an increase in percentage cooking loss, it needed to be determined if stimulation would have an effect.

Evaluation of the percentage cooking loss data presented in Table VII and Figure 13 showed that differences in moisture content of stimulated versus control chops from all muscles were not statistically significant ($P > .05$) in the main plot. Appendix (Tables XVI, XVII) data showed some statistically significant position by treatment interaction in the Longissimus Dorsi, Semimenbranosus and Semitendinosus.

Evaluation by Taste Panel

A review of Table 85 as shown in Kramer and Twigg (1970) revealed that 38 correct duo-trio pairings out of 60 possible were required to achieve a significant difference at the five percent level. As shown in Table VIII, this criterion was met for the Biceps Femoris and it approaches significance for the Semimembranosus and Longissimus Dorsi. This indicated that the judges could distinguish differences between stimulated and control chops from the muscles evaluated. Significance of the duo-trio test is not supported by the shear force data. Significance found in taste panel evaluation could only be explained by differences in cooking, connective tissue, and human or experimental error.

TABLE VII

PERCENTAGE COOKING LOSS OF PORCINE MUSCLE
AS INFLUENCED BY ELECTRICAL CURRENT

Muscle	NOB[3]	Percentage Loss		EMS[1]	OSL[2]
		Control	Stimulated		
Biceps Femoris	60	17.88	18.51	53.03	0.55
Longissimus Dorsi	60	24.78	24.45	26.29	0.76
Psoas Major	60	24.95	24.29	4.15	0.58
Semimembranosus	60	24.80	24.66	104.67	0.88
Semitendinosus	60	26.19	27.19	15.56	0.34

* = ($P < .05$).

[1]Error Mean Square = Pig^X Treatment, D.F. = 9.

[2]Observed Significance Level.

[3]Number of Observations.

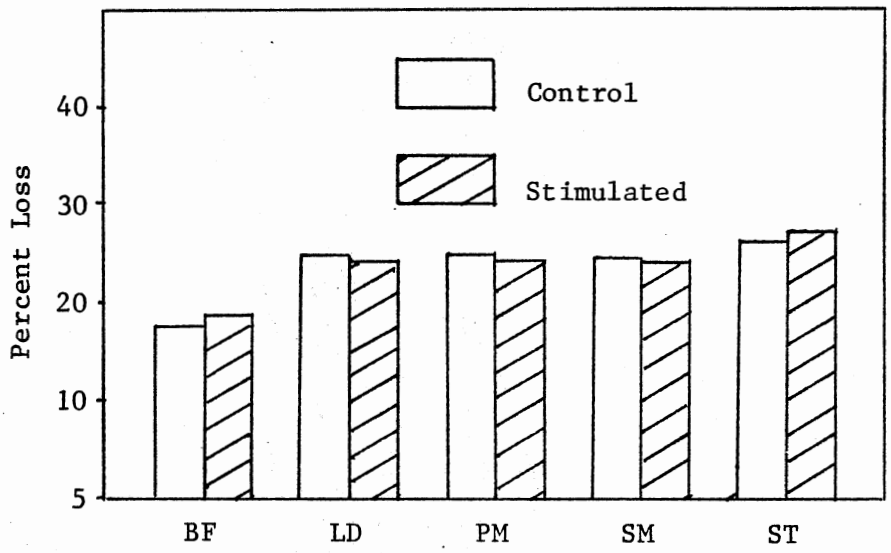

Figure 13. Percentage Cooking Loss of Porcine Muscle as Influenced by Electrical Current

TABLE VIII

PAIRED COMPARISON ANALYSIS AS INFLUENCED BY ELECTRICAL CURRENT

Muscle	Total Number of Paired Comparisons	Total Number Identifying Pair
Biceps Femoris	60	39*
Longissimus Dorsi	60	36
Semimembranosus	60	37

* = ($P < .05$).

CHAPTER V

SUMMARY AND CONCLUSIONS

Ten Yorkshire hogs were investigated to evaluate the effect of electrical current on hog boning of various muscles. One side of the ten carcasses was randomly assigned to 90 seconds of electrical stimulation of 300 volts with a frequency of 400 cycles per second and a duration of .5 milliseconds. This was followed by excision of the muscles at 30 minutes post-mortem from both the treated and control sides. Biceps Femoris, Longissimus Dorsi, Psoas Major, Semimembranosus and Semitendinosus muscles were analyzed in the investigation to evaluate color measured by Photovolt tristimulus reflective meter, pressed fluids determined by the use of the Carver Laboratory press, tenderness as measured by the Universal Instron Model 1122 for shear force and a trained taste panel. Percentage cooking loss was also determined.

Differences in color parameter values (L, a, b) between stimulated and nonstimulated treatments were small for the "L" values except for the Semitendinosus which was significantly higher for the stimulated treatment in the main plot. Parameter "a" was statistically significant for Semimembranosus treated and parameter "b" was statistically significant for the Semimembranosus control. Position by treatment interaction was statistically significant for the "L" value of the Longissimus Dorsi muscle, the "a" value had no statistical significance, but the "b" value for the Semitendinosus was statistically

significant.

Press fluid ratio and percentage cooking loss in the main plot had no statistically significant difference between treatments. Position by treatment interaction of the Biceps Femoris and Psoas Major were significant ($P < .05$) for the pressed fluid. Percentage cooking loss for the Longissimus Dorsi, Semimembranosus and Semitendinosus were found to be statistically significant. However, these data being statistically significant have little value from the practical aspect since they only occur at one position and the position is different for each muscle.

Shear force data of the main plot showed no statistically significant difference between control and treatment. Position by treatment interaction had some statistical significance ($P < .05$) in the Semitendinosus, Psoas Major and Biceps Femoris. Looking at its occurrence in only one position of each individual muscle, it has little practical value and is possibly due more to within muscle variation and other factors.

The trained taste panel detected variations in tenderness and matched up the duo-trio test significantly ($P < .05$) correct for Biceps Femoris and approached it on the Longissimus Dorsi and Semimembranosus. These findings did not support the shear force data.

Further research is now necessary to determine the electrical parameters which impose the largest effect and to determine the combination or exact mechanism in the muscle which is affected so the two could be combined to achieve the maximum effect.

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APPENDIX

TABLE IX

COLOR PARAMETERS FOR PORK MUSCLE AS INFLUENCED BY ELECTRICAL STIMULATION AND POSITION

Biceps Femoris L-Value

Pos[1] / Trt[2]	4	5	6	Mean
C[4]	82.0[3]	81.5	83.8	82.4
S[5]	81.9	81.2	81.4	81.5
Mean	81.9	81.3	82.6	82.0

Main Plot EMS=50.42, df=9
Sub Plot EMS=7.94, df=36

Biceps Femoris a-Value

Pos / Trt	4	5	6	Mean
C	9.1	9.2	9.9	9.4
S	10.8	9.5	7.8	9.4
Mean	9.9	9.3	8.9	9.4

Main Plot EMS=30.72, df=9
Sub Plot EMS=28.30, df=36

Biceps Femoris b-Value

Pos / Trt	4	5	6	Mean
C	19.6	18.0	15.2	17.6
S	17.2	17.6	16.7	17.2
Mean	18.4	17.8	16.0	17.4

Main Plot EMS=16.27, df=9
Sub Plot EMS=16.78, df=36

1) Position of chop; 2) Treatment; 3) 10 observations per cell; 4) Control; 5) Electrical stimulation

Longissimus Dorsi L-Value

Pos / Trt	4	5	6	Mean
C	89.0	90.6	91.0	90.2
S	90.3	91.4	89.0	90.2
Mean	89.6	91.0	90.0	90.2

Main Plot EMS=5.57, df=9
Sub Plot EMS=5.72, df=36

Longissimus Dorsi a-Value

Pos / Trt	4	5	6	Mean
C	8.9	10.5	16.0	11.8
S	8.3	7.7	8.9	8.3
Mean	8.6	9.1	12.5	10.0

Main Plot EMS=98.61, df=9
Sub Plot EMS=127.37, df=36

Longissimus Dorsi b-Value

Pos / Trt	4	5	6	Mean
C	14.2	14.2	17.4	15.3
S	16.3	16.2	15.0	15.8
Mean	15.2	15.2	16.2	15.5

Main Plot EMS=7.74, df=9
Sub Plot EMS=15.67, df=36

TABLE X

COLOR PARAMETERS FOR PORK MUSCLE AS INFLUENCED BY ELECTRICAL STIMULATION AND POSITION

Psoas Major L-Value

Pos[1] / Trt[2]	4	5	6	Mean
C[4]	75.1	79.3	77.8	77.4
S[5]	79.0	79.6	75.2	77.9
Mean	77.1	79.4	76.5	77.7

Main Plot EMS=14.46, df=9
Sub Plot EMS=32.86, df=36

Psoas Major a-Value

Pos / Trt	4	5	6	Mean
C	18.0	12.6	17.5	16.1
S	12.6	9.6	23.3	15.2
Mean	15.3	11.1	20.4	15.6

Main Plot EMS=63.04, df=9
Sub Plot EMS=214.18, df=36

Psoas Major b-Value

Pos / Trt	4	5	6	Mean
C	13.6	16.2	16.0	15.3
S	15.6	17.6	13.0	15.4
Mean	14.6	16.9	14.5	15.3

Main Plot EMS=13.36, df=9
Sub Plot EMS=25.66, df=36

1) Position of chop; 2) Treatment; 3) 10 observations per cell; 4) Control; 5) Electrical stimulation

Semimembranosus L-Value

Pos / Trt	4	5	6	Mean
C	81.8	82.5	80.8	81.7
S	82.4	80.8	79.7	81.0
Mean	82.1	81.6	80.2	81.3

Main Plot EMS=31.82, df=9
Sub Plot EMS=11.54, df=36

Semimembranosus a-Value

Pos / Trt	4	5	6	Mean
C	11.9	8.9	9.9	10.3
S	13.8	13.5	13.0	13.4
Mean	12.8	11.2	11.5	11.8

Main Plot EMS=23.19, df=9
Sub Plot EMS=22.22, df=36

Semimembranosus b-Value

Pos / Trt	4	5	6	Mean
C	15.5	18.0	14.7	16.1
S	14.6	12.7	13.6	13.7
Mean	15.1	15.3	14.2	14.9

Main Plot EMS=4.82, df=9
Sub Plot EMS=20.35, df=36

TABLE XI

COLOR PARAMETERS FOR PORK MUSCLE AS INFLUENCED BY ELECTRICAL STIMULATION AND POSITION

Semitendinosus L-Value

Trt[2] \ Pos[1]	4	5	6	Mean
C[4]	78.7[3]	78.3	78.2	78.4
S[5]	83.3	80.2	84.0	82.5
Mean	81.0	79.2	81.1	80.4

Main Plot EMS=48.64, df=9
Sub Plot EMS=16.41, df=36

Semitendinosus a-Value

Trt \ Pos	4	5	6	Mean
C	13.4	15.4	11.2	13.3
S	11.4	12.8	10.6	11.6
Mean	12.4	14.1	10.9	12.5

Main Plot EMS=102.26, df=9
Sub Plot EMS=61.28, df=36

Semitendinosus b-Value

Trt \ Pos	4	5	6	Mean
C	13.1	16.4	15.5	14.9
S	15.8	15.6	20.2	17.2
Mean	14.4	16.0	17.9	16.1

Main Plot EMS=35.40, df=9
Sub Plot EMS=10.43, df=36

1) Position of chop; 2) Treatment; 3) 10 observations per cell; 4) Control; 5) Electrical stimulation

TABLE XII

PRESSED FLUIDS FOR PORK MUSCLE AS INFLUENCED BY ELECTRICAL STIMULATION AND POSITION

Biceps Femoris (cm^2)

Trt[2] \ Pos[1]	1	2	3	Mean
C[4]	29.0[3]	29.7	30.3	29.7
S[5]	30.3	29.7	29.7	29.7
Mean	29.7	29.7	30.3	29.7

Main Plot EMS=1.90, df=9
Sub Plot EMS=4.48, df=36

Longissimus Dorsi (cm^2)

Trt \ Pos	1	2	3	Mean
C	29.0	29.7	29.7	29.7
S	30.3	29.7	29.7	29.7
Mean	29.7	29.7	29.7	29.7

Main Plot EMS=1.48, df=9
Sub Plot EMS=6.65, df=36

Psoas Major (cm^2)

Trt \ Pos	1	2	3	Mean
C	32.9	31.6	32.3	32.3
S	32.3	30.3	32.3	31.6
Mean	32.3	31.0	32.3	31.6

Main Plot EMS=10.97, df=9
Sub Plot EMS=6.04, df=36

1) Position of chop; 2) Treatment; 3) 10 observations per cell; 4) Control; 5) Electrical Stimulation

Semimembranosus (cm^2)

Trt \ Pos	1	2	3	Mean
C	30.3	29.7	30.3	29.7
S	29.7	29.0	30.3	27.9
Mean	29.7	29.7	30.3	29.7

Main Plot EMS=12.45, df=9
Sub Plot EMS=7.23, df=36

Semitendinosus (cm^2)

Trt \ Pos	1	2	3	Mean
C	30.3	31.0	30.3	30.3
S	31.6	31.0	31.6	31.6
Mean	31.0	31.0	31.0	31.0

Main Plot EMS=6.71, df=9
Sub Plot EMS=7.03, df=36

TABLE XIII

PEAK AND TOTAL SHEAR FORCE FOR PORK MUSCLE AS INFLUENCED BY ELECTRICAL STIMULATION AND POSITION

Biceps Femoris Peak Force (kg/g)

Pos[1] / Trt[2]	1	2	3	4	5	6	Mean
C[4]	7.1[3]	7.9	9.3	9.4	9.8	10.1	8.9
S[5]	6.5	7.8	9.3	10.4	10.4	10.8	9.2
Mean	6.8	7.9	9.3	9.9	10.1	10.5	9.1

Main Plot EMS=1.34, df=9
Sub Plot EMS=2.16, df=90

Biceps Femoris Total Force (kg/cm^2)

Pos / Trt	1	2	3	4	5	6	Mean
C	53.2	58.0	56.2	50.5	46.8	47.2	52.0
S	55.0	55.5	49.9	48.8	49.7	51.5	51.7
Mean	54.1	56.8	53.1	49.7	48.3	49.3	51.9

Main Plot EMS=72.26, df=9
Sub Plot EMS=47.01, df=90

1) Position of chop; 2) Treatment; 3) 10 observations per cell; 4) Control; 5) Electrical Stimulation

Longissimus Dorsi Peak Force (kg/g)

Pos / Trt	1	2	3	4	5	6	Mean
C	8.4	6.7	8.8	6.9	8.0	6.5	7.6
S	7.7	6.6	7.4	6.8	7.0	6.7	7.0
Mean	8.0	6.6	8.1	6.9	7.5	6.6	7.3

Main Plot EMS=8.47, df=9
Sub Plot EMS=2.92, df=90

Longissimus Dorsi Total Force (kg/cm^2)

Pos / Trt	1	2	3	4	5	6	Mean
C	45.5	41.2	43.1	42.0	41.3	38.8	42.0
S	46.3	42.5	42.2	41.4	40.4	40.7	42.3
Mean	45.9	41.9	42.7	41.7	40.9	39.8	42.1

Main Plot EMS=43.24, df=9
Sub Plot EMS=16.90, df=90

TABLE XIV

PEAK AND TOTAL SHEAR FORCE FOR PORK MUSCLE AS INFLUENCED BY ELECTRICAL STIMULATION AND POSITION

Psoas Major Peak Force (kg/g)

Trt[2] \ Pos[1]	1	2	3	4	5	6	Mean
C[4]	6.7[3]	6.4	6.2	5.8	6.0	5.9	6.2
S[5]	7.4	7.2	6.2	6.4	6.1	6.2	6.6
Mean	7.0	6.8	6.2	6.1	6.0	6.0	6.4

Main Plot EMS=1.28, df=9
Sub Plot EMS=2.60, df=90

Psoas Major Total Force (kg/cm^2)

Trt \ Pos	1	2	3	4	5	6	Mean
C	58.8	59.3	58.4	51.2	54.6	50.6	55.5
S	60.7	62.0	50.4	59.3	55.2	49.9	56.2
Mean	59.8	60.6	54.4	55.2	54.9	50.2	55.9

Main Plot EMS=334.59, df=9
Sub Plot EMS=131.36, df=90

1) Position of chop; 2) Treatment; 3) 10 observations per cell; 4) Control; 5) Electrical stimulation

Semimembranosus Peak Force (kg/g)

Trt \ Pos	1	2	3	4	5	6	Mean
C	8.4	8.3	8.7	8.6	8.4	9.1	8.6
S	7.6	9.4	9.9	9.1	8.9	10.3	9.2
Mean	8.0	8.8	9.3	8.9	8.7	9.7	8.9

Main Plot EMS=9.65, df=9
Sub Plot EMS=2.96, df=90

Semimembranosus Total Force (kg/cm^2)

Trt \ Pos	1	2	3	4	5	6	Mean
C	45.9	47.0	48.6	45.0	46.4	46.6	46.6
S	50.7	48.3	55.9	45.7	43.2	47.3	48.5
Mean	48.3	47.7	52.2	45.3	44.8	47.0	47.6

Main Plot EMS=59.27, df=9
Sub Plot EMS=40.13, df=90

TABLE XV

PEAK AND TOTAL SHEAR FORCE FOR PORK MUSCLE AS INFLUENCED BY ELECTRICAL STIMULATION AND POSITION

Semitendinosus Peak Force (kg/g)

Trt[2] \ Pos[1]	1	2	3	4	5	6	Mean
C[4]	6.5[3]	6.2	6.2	6.1	6.3	7.1	6.4
S[5]	7.0	6.0	5.6	5.3	5.9	7.6	6.2
Mean	6.8	6.1	5.9	5.7	6.1	7.4	6.3

Main Plot EMS=2.63, df=9
Sub Plot EMS=2.08, df=90

Semitendinosus Total Force (kg/cm^2)

Trt \ Pos	1	2	3	4	5	6	Mean
C	42.4	50.4	51.9	50.5	48.6	50.9	49.1
S	45.2	51.7	49.9	47.1	40.3	50.9	49.2
Mean	43.8	51.1	50.9	48.8	49.5	40.9	49.2

Main Plot EMS=55.23, df=9
Sub Plot EMS=51.51, df=90

1) Position of chop; 2) Treatment; 3) 10 observations per cell; 4) Control; 5) Electrical stimulation

TABLE XVI

COOKING LOSS OF PORK MUSCLES AS INFLUENCED BY ELECTRICAL STIMULATION AND POSITION

Biceps Femoris

Trt[2] \ Pos[1]	1	2	3	4	5	6	Mean
C[4]	26.3[3]	30.1	28.3	29.9	32.4	33.3	30.1
S[5]	27.0	28.4	31.8	32.7	32.6	34.2	31.1
Mean	26.7	29.3	30.0	31.3	32.5	33.8	30.6

Main Plot EMS=53.04, df=9
Sub Plot EMS=42.73, df=90

Longissimus Dorsi

Trt \ Pos	1	2	3	4	5	6	Mean
C	24.7	25.0	26.2	27.5	29.7	29.9	27.2
S	25.3	25.9	27.4	28.9	27.3	26.4	26.9
Mean	25.0	25.4	26.8	28.2	28.5	28.2	27.0

Main Plot EMS=26.29, df=9
Sub Plot EMS=9.94, df=90

1) Position of chop; 2) Treatment; 3) 10 observations per cell; 4) Control; 5) Electrical stimulation

Psoas Major

Trt \ Pos	1	2	3	4	5	6	Mean
C	7.6	7.7	7.3	7.7	9.1	8.5	8.0
S	7.1	6.6	7.2	8.2	8.7	8.6	7.8
Mean	7.3	7.1	7.3	8.0	8.9	8.5	7.9

Main Plot EMS=4.15, df=9
Sub Plot EMS=1.67, df=90

TABLE XVII

COOKING LOSS OF PORK MUSCLES AS INFLUENCED BY ELECTRICAL STIMULATION AND POSITION

Semimembranosus

Trt[2] \ Pos[1]	1	2	3	4	5	6	Mean
C[4]	33.3[3]	42.6	45.3	52.6	52.8	51.2	46.3
S[5]	26.4	37.5	45.3	51.7	57.2	58.1	46.0
Mean	29.8	40.0	45.3	52.1	55.0	54.6	46.2

Main Plot EMS=104.67, df=9
Sub Plot EMS=132.33, df=90

Semitendinosus

Trt \ Pos	1	2	3	4	5	6	Mean
C	13.1	17.8	22.9	22.6	22.1	17.8	19.4
S	16.4	19.8	21.4	22.4	21.2	19.5	20.1
Mean	14.8	18.8	22.2	22.5	21.7	18.7	19.8

Main Plot EMS=15.56, df=9
Sub Plot EMS=11.48, df=90

1) Position of chop; 2) Treatment; 3) 10 observations per cell; 4) Control; 5) Electrical stimulation

VITA

Joseph Thomas Thompson

Candidate for the Degree of

Master of Science

Thesis: THE EFFECT OF ELECTRICAL CURRENT ON HOT BONED PORK QUALITY

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