

THE EFFECT OF POSTMORTEM ELECTRICAL STIMULATION ON THE
TEXTURE OF HOT-BONED, CHILL-BONED, AND AGE-BONED
BROILER BREAST FILLETS

BY

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Major Department: Food Science and Human Nutrition

Two experiments were conducted to determine the effects of postmortem electrical stimulation of broiler carcasses (240V for 0, 15, 30, or 45 seconds; 0, 240, 530, or 820V for 15 seconds) on the tenderness of broiler breast meat harvested immediately after feather removal (hot-boned), after chilling (chill-boned), or after a 48-hour aging period (age-boned).

Postmortem electrical stimulation of broiler carcasses, regardless of the stimulation voltage or duration, had no significant effect on the tenderness of hot-boned or age-boned broiler breast meat. High voltage stimulation (820V) significantly improved the tenderness of chill-boned broiler breast meat, producing an acceptably tender product.

Electrical stimulation increased the rate of rigor development as demonstrated by higher R-values and lower pH values of hot-boned and

chill-boned fillets from stimulated versus nonstimulated carcasses. The ultimate pH or R-value of the meat was not affected by stimulation treatment. High voltage stimulation (530 and 820) of carcasses caused increased sarcomere lengths in hot-boned and chill-boned fillets. Tenderness improvements associated with longer sarcomeres were observed in the chill-boned fillets, but not in hot-boned fillets where increased sarcomere lengths were offset by decreases in the fragmentability of the myofibrils. The fragmentation index of chill-boned fillets was not significantly affected by high voltage stimulation ($P < 0.05$) but was correlated to tenderness, indicating increased fragmentability did play a role in tenderization.

Low voltage stimulation (240V) did not significantly affect the fragmentation index of hot-boned or chill-boned fillets, or the sarcomere lengths hot-boned fillets. Low voltage stimulation had an inconsistent effect on sarcomere lengths, with increases in one experiment but not the other.

Regardless of stimulation voltage or duration, electrical stimulation did not significantly affect sarcomere lengths or fragmentation indexes of age-boned poultry meat. The percent water uptake, driploss, cookloss, or cooked meat moisture of hot-boned, chill-boned, or age-boned was not significantly affected by electrical stimulation.

CHAPTER I INTRODUCTION

In the past decade there has been an increasing trend to market whole fresh eviscerated broiler carcasses as further processed products. Cut-up parts such as breast fillets, breasts, and drumsticks that sell for premium prices compared to the whole carcass are viewed as high value marketable products.

In the last few years, however, a dramatic change has occurred in industry orientation, which is referred to as the "Third Great Revolution" for the broiler industry. The industry has increased its production of convenience food items for use at home in conventional and microwave ovens. More importantly, the demand for deboned broiler meat has increased tremendously as a result of the development of restructured boneless product for use in the fast food industry. Haffert (1984) estimated that by mid-1985 the demand for boneless meat would expand by 2 million pounds per week in the U.S. as a result of new product introductions in the fast food/takeout industry.

In an attempt to efficiently meet this increased demand for deboned meat, many processors debone the meat immediately after chilling. Consumer response has indicated that this technique causes wide variation in the tenderness of the meat with a large portion of the meat being unacceptably tough. This effect has been documented in scientific literature (Sams, 1984; Lyon et al., 1985). Lyon et al.

(1985) demonstrated that a minimum aging period of 4 to 6 hours was required to avoid the toughening that occurred with chill-boning. Shelton (1985) estimated that, by the year 2000, 90% of poultry will be marketed as cut-up or boned product, but tenderness problems associated with chill-boning will force processors to adopt a minimum 4-hour aging period prior to boning. This aging period has resulted and will result in increased production costs due to increased labor, handling and storage requirements.

An alternate harvesting procedure has been suggested by D. Hamm (1981, 1982) and Hamm and Thomson (1983), which they refer to as hot-stripping, or the removal of a muscle or muscle system prior to chilling (West, 1983). Current processing techniques involve exsanguination, feather removal, evisceration, and chilling of the whole carcass, followed by any desired processing and packaging. D. Hamm's proposed technique involves the hot-boning of the defeathered, but noneviscerated carcass. The breast, wing, and leg quarter would be removed from the carcass for marketing while the remaining portions would be rendered for use in poultry feeds. Hot-boning would result in substantial savings compared to more conventional harvest for a number of reasons. The evisceration line would be eliminated, thus reducing the expense of the evisceration equipment and the personnel involved in that portion of the line. The major savings, however, would be in chilling and refrigeration. It is estimated that chilling expenses would be cut by 55-60% by chilling only the premium priced portions. The tonnage of meat requiring chilling would be reduced,

thus lowering the biochemical oxygen demand costs associated with the chiller water (D. Hamm, 1982).

Like chill-boning, hot-boning has a deleterious effect on the texture of poultry meat (de Fremery and Pool, 1960; Klose et al., 1972; Lyon et al., 1973; Peterson, 1977; Sams, 1984; Stewart et al., 1984b), which is even more severe than that found in chill-boned meat. Results from numerous studies have indicated that some tenderizing treatment is needed if hot- or chill-boning is to be utilized successfully by the poultry industry. One possible method involves the use of postmortem electrical stimulation.

Postmortem electrical stimulation is commonly used in the beef and lamb industry today. This method has a long history of experimentation dating back to the mid-1700s when Ben Franklin noted that turkeys killed by electrocution were "uncommonly tender." Nearly 200 years later Harsham and Deatherage (1951), working with Kroger Co. and Westinghouse, received a patent for the use of electrical stimulation as a means of tenderizing beef. Their work went virtually unnoticed until the 1970s when Carse (1973) utilized electrical stimulation as a means of avoiding cold shortening in lambs. Experimentation continued and the New Zealand lamb industry quickly adopted the method as a means of avoiding cold and thaw shortening that had been occurring in lambs that were frozen immediately after slaughter for shipment overseas. The technique was soon adopted by the beef industry as a means of hastening rigor development, thereby reducing the risks of cold and thaw shortening, allowing for

hot-boning, reducing the occurrence of heat rings, and improving the tenderness and color of meat (Pearson and Dutson, 1985).

Little work has been published examining the effects of electrical stimulation on tenderness of poultry meat. Until recently there was little reason for the broiler industry to be overly concerned about the tenderness of poultry meat because it was generally considered very tender. New consumer demands and processing techniques designed to better serve the consumer and the processor have created very real texture problems. Maki and Froning in 1984 stimulated turkey with 800 volts and found improvements in texture and color compared to unstimulated controls. A British team, however, found electrical stimulation of turkeys with 94 volts had virtually no effect on the texture of the breast meat (Dransfield et al., 1984).

The objectives of this research project were to

1. examine the effect of electrical stimulation on the texture of hot-boned, chill-boned and age-boned broiler breast meat;
2. establish an optimal stimulation voltage and duration in order to achieve a maximum tenderness effect for each boning time;
3. examine some physical and biochemical changes that occur as a result of electrical stimulation.

CHAPTER II
REVIEW OF THE LITERATURE

Effects of Hot- and Chill-Boning on the
Texture of Poultry Meat

Several investigators have noted that cutting carcasses into parts or removing the muscle from the bone prior to rigor onset and chilling (hot-boning), or immediately after chilling and prior to rigor resolution (chill-boning), causes increased toughness in poultry meat compared to meat boned after aging (de Fremery and Pool, 1960; Klose et al., 1972; Lyon et al., 1973, 1985; Wyche and Goodwin, 1974; Peterson, 1977; D. Hamm, 1983; Sams, 1984). Many poultry processors currently utilize chill-boning in spite of the textural problems encountered, but hot-boning or hot-stripping is an experimental technique currently not in use by the industry. As opposed to age-boning, the two techniques are more desirable ways for the processor to obtain boned and cut-up parts, due to savings accrued through reduced labor, handling and storage requirements (D. Hamm, 1982). Although consumer demand and processor interest in boned meat have only recently heightened, researchers have long examined the effects of various prerigor and post-chill harvesting schemes on the texture of poultry meat.

Lowe (1948) found that the tenderness of an uncut breast muscle was considerably better than the tenderness of the opposite muscle which was cut across the fibers prior to the onset of rigor, even

though the carcasses were aged for 24 hours prior to roasting. She noted that if the muscle was cut after the onset of rigor the increase in toughness did not occur. Klose et al. (1972) demonstrated that toughness was induced in broiler breast meat by removing the wings at the shoulder joint up to 2 hours postmortem. The hot-cut muscle had shear values approximately twice that of muscle that was cut in a similar manner after a 22-hour chilling period. Cutting the wing off beyond the insertion of the breast muscle immediately after slaughter, however, alleviated the toughening effect. Webb and Brunson (1972) noted similar findings while examining the effects of line trimming on tenderness. Cutting the breast muscle or cutting through the wing joint substantially increased shear values of the Pectoralis superficialis, while cutting the wing distal to the shoulder did not.

Klose et al. (1972) found that cutting carcasses into parts prior to chilling significantly increased the shear values of light and dark meat compared to carcasses that were cut-up after chilling and a 6 hour aging period. Similar results were obtained even if the hot-cut parts were aged for up to 3 days postmortem prior to roasting. The same trend was observed in commercially processed carcasses, but the carcasses processed in the laboratory had much lower shear values than those processed in the commercial setting. These differences were attributed to a more extensive commercial picking regime compared to that found in the laboratory.

Wyche and Goodwin (1974) found only small differences in the shear values of light and dark meat obtained from hot-cut or chill-cut (cut-up immediately after chilling) samples aged for 24 hours prior to

cooking, although taste panelists identified the hot-cut samples as significantly tougher than the chill-cut samples. They also found that shear values increased as the aging time after cutting increased up to 4 hours, then declined and remained constant after 8 hours of aging. Differences in the tenderness of hot-cut and chill-cut samples were larger with shorter aging periods but after 24 hours the differences were very small. The apparent conflict in the results obtained by Klose et al. (1972) and Wyche and Goodwin (1974) could be attributed to the use of different cutting procedures. Lyon et al. (1973) found no differences in the shear values of breast meat obtained from hot-cut or age-cut (aged 48 hours prior to cutting) carcasses for five different commercial cutting procedures. However, two other cutting methods, which involved transverse cuts across the breast muscle, caused significant increases in toughness in hot-cut samples compared to age-cut samples. Secondly, the time of chill-boning was considerably different in the two studies. Lyon et al. (1985) found that boning or cutting meat from carcasses 4 or more hours postmortem significantly reduced shear values compared to those of carcasses boned prior to this time.

Numerous studies have been conducted examining the causes of the toughening associated with hot- and chill-boning. De Fremery and Pool (1960) examined the effects of various treatments, such as hot-stripping, mechanical stimulation, freezing, thawing, exhaustive electrical stimulation, and irradiation on prerigor meat. All treatments caused increased toughness compared to untreated samples, and this toughness appeared to be related to a more rapid onset of

rigor mortis whether measured by breakdown of adenosine triphosphate (ATP) or glycogen, drop in pH, or the loss of extensibility. It was not clear if the toughening was directly attributed to ATP, glycogen, or pH changes. In an attempt to partially answer this question muscles were injected antemortem with sodium monobromate which caused a rapid decrease in ATP but only small decreases in pH or glycogen. Injected muscles were found to be as tender as untreated muscles, but the ultimate pH of the treated muscle was much higher (> 6.5) than the untreated (5.8). These results indicated that toughening was not directly related to rapid ATP depletion but was related to changes in glycogen levels and pH.

The influence of postmortem glycolysis on the tenderness of poultry meat was examined by de Fremery and Pool (1963). Postmortem glycolysis was prevented or minimized in fryers and turkey hens by subcutaneous antemortem injection of epinephrine, injection of sodium iodoacetate, or cooking immediately after slaughter. Antemortem epinephrine injections caused a more rapid rate of postmortem ATP depletion, and an increased rate of rigor onset compared to controls, but breast meat from the injected carcasses had significantly lower shear values than the controls. In a previous study, in 1960, de Fremery and Pool suggested that toughness was induced by a more rapid rate of rigor onset. They suggested that differences in tenderness were related to the ultimate pH of the meat. The control birds, which proceeded through normal postmortem glycolysis, had a significantly lower pH of 5.71 compared to a pH of 6.56 in the epinephrine-treated carcasses. Glycogen levels in the muscles of the treated carcasses

were drastically reduced prior to slaughter; thus the birds had less substrate for glycolysis and did not produce typical amounts of lactic acid, accounting for the substantially increased ultimate pH of the treated carcasses.

Results similar to those found in the experiment conducted by de Fremery and Pool (1960) were obtained when glycolysis was inhibited by sodium iodoacetate, and cooking within 2 minutes postslaughter. The shear values of the controls were significantly higher than those of the treated carcasses. As in the previous experiment, the pH of the muscle in which glycolysis was inhibited was higher than the pH of the controls. Additionally, the carcasses which were cooked immediately after slaughter had much lower shear values than carcasses cooked 1 hour postmortem.

Results from these two experiments by de Fremery and Pool (1960, 1963) indicated that the depletion of ATP did not directly affect the texture of the muscle, but that textural changes were related to changes that occurred in the muscle as a result of postmortem glycolysis. Also, they demonstrated that a decrease in glycogen levels in the muscles was not directly responsible for textural changes that occurred postmortem, since in one experiment, glycogen levels were depleted without an accompanying increase in toughness.

Khan and Nakamura (1970) used antemortem epinephrine injections and unrestricted pre- and post-slaughter struggle as a means of varying the amount of lactic acid found in broiler breast tissue after slaughter. Antemortem injections of epinephrine served to deplete glycogen stores, thus reducing lactic acid formation while

unrestricted struggle increased the amounts of lactic acid found after slaughter. They found that as the lactic acid concentration in the muscles 24 hours after slaughter increased, so did shear values as a hyperbolic function, indicating that the texture of meat was related to lactic acid concentration, thus the pH of the meat.

In order to relate changes in pH to the texture of hot-boned meat, Peterson (1977) used antemortem sodium polyphosphate injections to reduce lactic acid levels in hot-cut carcasses and compared them to samples cut up after a 24-hour aging period. Hot-cut samples had significantly higher shear values than the age-cut samples, but the hot-cut samples from injected carcasses were as tender as the controls. The differences in tenderness appeared to be related to the ultimate pH of the breast muscle. As in the previously discussed study by de Fremery and Pool (1963), it seemed that the toughening effect was related to a lower ultimate pH, but Peterson suggested that the rate of pH decline was responsible for textural changes, not just the ultimate pH.

Stewart et al. (1983, 1984b) found that hot-boned or severed (muscle was severed at the insertion) Pectoralis superficialis muscle exhibited a slower rate of pH decline than intact muscle, even though no difference in temperature existed between the three treatments. The authors postulated that the slower rate of pH decline found in the hot-boned and severed muscle resulted from severing muscle attachments which allowed the muscle to undergo unimpeded contraction, decreasing the need for ATP upon stimulation which, in turn, reduced the rate of anaerobic glycolysis or the rate of pH decline.

Stewart et al. (1984a), in a second study, found that the shear force of excised (prerigor) muscle was negatively and highly correlated to the time of excision postmortem, as was the pH of the excised muscle. The authors postulated, however, that the relationship between pH at time of boning and shear value was not of a direct cause and effect nature, but that they were related to similar postmortem biochemical occurrences, particularly since the ultimate pH of hot-boned muscle was similar to that of age-boned.

In another experiment, carcasses were chilled prior to excision at 4 hours postmortem. Excised muscle had significantly higher pH and shear values than control halves chilled and boned 24 hours postmortem (Stewart et al., 1985a). In a similar experiment Lyon et al. (1985) boned broiler breast halves at various times post-chill and found that the most rapid pH decline occurred within 1 hour postmortem and that pH and shear values decreased to control levels when boning occurred at least 4 hours post-chill. Results from both experiments indicated that chilling prior to boning slowed rigor development and increased the holding time postmortem required to alleviate toughness caused by chill-boning when compared to holding times for hot-boned (nonchilled) muscle. It appeared that a holding period of at least 4 hours post-chill was required to alleviate toughening found with chill-boning, whereas a 2 to 4 hour holding period postmortem was required to alleviate toughness in unchilled, hot-boned meat.

Effects of Hot-Boning on the Texture of Bovine Muscle

Kastner et al. (1973) and Falk et al. (1975) suggested that the release of physical anatomical restraints prior to the onset of rigor resulted in increased shortening upon the onset of rigor which in turn increased toughness. Kastner et al. (1973) obtained shear values of muscles from one side of a carcass held at 16°C and hot-boned at 2, 5, or 8 hours postmortem and compared these to values for muscle cut from the other side of the carcass after 48 hour aging. Muscles boned at 2 and 5 hours postmortem were significantly tougher than the corresponding controls, whereas muscle hot-boned at 8 hours was as tender as the controls. The authors attributed this difference to the fact that boning at 2 and 5 hours postmortem occurred prior to the onset of rigor, but 8 hour boning occurred after the onset of rigor. Jungk et al. (1967) found that maximum isometric tension development related with rigor mortis occurred 3 to 5 hours postmortem, agreeing with Kastner's hypothesis. Falk et al. (1975), in an evaluation of hot-boned beef boned at 3, 5, and 7 hours postmortem, found no significant differences between hot-boned and matching control sides that were boned after a 48 hour aging period at 2°C. Because the hot-boned samples had a mean pH of 5.76 and a maximum rate of temperature decline around 3 hours postmortem, the authors suggested that no differences in tenderness were found because the carcasses were already in rigor by 3 hours postmortem.

Tarrant (1977) examined the effects of hot boning on the rate of glycolysis by removing the m. semimembranosus from beef carcasses within one hour postmortem. The hot-boned muscle was held at 10°C for

24 hours to avoid cold shortening while the control carcasses were held at 3°C. Temperature and pH were monitored at 1.5, 5, and 8 cm from the surface of the muscle. It was found that hot-boning increased the cooling rates of the hot-boned muscles over intact muscles, by increasing the cooling rates at 5 and 8 cm, and slightly decreasing the rate at the surface. By 6 hours postmortem the temperature throughout the hot-boned muscle was approximately 14°C, while only the surface temperature of the intact muscle was decreased to 14°C. The initial pH of both muscles at 1 hour postmortem was 6.8. The rate of pH decline, however, was very different for the hot-boned and intact muscles. Rates of pH decline up to 6 hours postmortem for the hot-boned carcasses were 0.07, 0.11, and 0.07 pH units/hour at 1.5, 5, and 8 cm, respectively, compared to 0.07, 0.16, and 0.25 pH units/hour in the intact muscle. In the hot-boned muscles the ultimate pH was reached in 24 hours while intact muscle reached the ultimate pH in 6, 12, 24-48 hours at 8, 5, and 1.5 cm, respectively. Hot-boning caused an immediate and significant decrease in creatine phosphate at 5 and 8 cm, possibly a result of muscle stimulation upon excision, but the ATP content immediately after boning was similar to that in the intact muscle. Additionally, it was shown that at both 8 and 5 cm from the muscle surface, hot-boned muscle had much slower ATP depletion rates but a slightly increased depletion rate at the muscle surface compared to the intact muscle. The hot-boned muscle in general had a slow and uniform onset of rigor mortis throughout the whole muscle, while the intact muscle had varying rates of rigor onset with the interior having a higher

temperature and faster rate of rigor onset compared to the intermediate depth. The outer portion of the intact muscle had a low temperature and a relatively high pH, conditions which are associated with cold shortening and increased toughness.

Tarrant's study demonstrated the profound influence of temperature on postmortem rigor development. De Fremery and Pool (1960) found that decreasing holding temperatures of prerigor poultry meat from 40°C to 10°C caused a decline in the rate of ATP depletion, or rigor development. Below 10°C, however, the rate of ATP depletion increased. Similar phenomena have been observed in prerigor bovine muscle with the rates of ATP depletion decreasing as temperature declined from 30 to 2°C. Below 2°C the ATP depletion rate dramatically increased (Jolley et al., 1981). Locker and Hagyard (1963) found that at 0 to 2°C a rapid and extreme shortening of isolated prerigor beef muscle occurred (47.7% of the original length). Above 2°C the extent of the shortening decreased reaching a minimum between 14 and 19°C.

Marsh and Leet (1966) documented the relationship between the degree of muscle shortening and meat tenderness demonstrating that as muscle shortened 20 to 40% of the original length, shear values increased 3 to 4 times over values observed for nonshortened muscle. When muscles were shortened more than 40%, however, shear values decreased to those associated with nonshortened muscles leveling off at 60% shortening. Tarrant (1977) demonstrated that hot-boning resulted in more rapid and uniform cooling of muscle, compared to intact muscles. Hot-boning allowed the meat to cool faster,

increasing the risk of achieving low temperatures ($< 10^{\circ}\text{C}$) prior to the onset of rigor, thus resulting in cold shortening and the accompanying increase in toughness.

Davey and Gilbert (1974) demonstrated that the trigger for cold shortening was the release of calcium ions. They found that muscle fibers did not cold shorten in the presence of ethylenediaminetetra-acidic acid (EDTA), and that calcium concentrations in the sarcoplasm reached 10^{-5} M before cold shortening occurred.

Whiting (1980) demonstrated that at 1°C , muscle mitochondria lost the ability to bind calcium and released calcium into the sarcoplasm. Typically, the sarcoplasmic reticulum (SR) would sequester the calcium lost from the mitochondria but the mitochondria released more calcium than the SR could possibly sequester. Additionally, workers have found that the calcium binding ability of the SR declined with decreasing temperatures due to an inactivation of the ATP-driven calcium pump that is responsible for regulating calcium levels in the sarcoplasm. With the inactivation of the pump, calcium levels in the sarcoplasm increased to the critical level cited by Davey and Gilbert (1974), and calcium reacted with the troponin-tropomyosin complex, initiating muscle contracture. If this occurred early postmortem, appreciable levels of ATP were present, allowing for muscle contracture in the prerigor muscle. As ATP levels declined there was a further reduction in the ability of the ATP-driven calcium pump in the SR to bind calcium. The calcium induced contraction would utilize ATP, causing the rates of ATP depletion in muscles held at low

temperatures (approx. 2°C) to be higher than rates found in muscle held at higher temperatures.

Effects of Electrical Stimulation on Meat Tenderness

One of the first documented cases using electricity as a tenderizing agent was reported by Benjamin Franklin in the 1700's, when he noted that chickens and turkeys killed by electrocution were "uncommonly tender" (Lopez and Herbert, 1975). Little work, however, has been conducted using electrical stimulation as a tenderizer of poultry muscle. Until recently, tenderness had not been a serious concern in the poultry industry, but with the advent of new processing techniques and a desire for greater uniformity in texture, methods to promote tenderness have received greater attention.

De Fremery and Pool (1960) found that exhaustive electrical stimulation of an excised Pectoralis superficialis muscle resulted in accelerated rates of ATP disappearance and pH decline. The Pectoralis superficialis muscles excised from six 11 week old broilers were exhaustively stimulated, and it was found that the excised stimulated muscle had higher shear values than the excised unstimulated controls. The muscle was excised prior to stimulation and was stimulated with voltages ranging from 20 to 360 volts for 15 to 30 minutes. Since the muscle was not physically restrained, electrical stimulation probably increased the toughness of the meat through extensive and exaggerated muscle shortening.

In contrast, Maki and Froning (1984) found that turkeys stimulated with 800 volts after bleeding had significantly more tender

breast meat than unstimulated controls. The stimulated muscle was also found to have longer sarcomere lengths and brighter color compared to the controls.

Judging from the two studies, electrical stimulation must be applied to the carcass while it is still intact to achieve tenderness and electrical stimulation of poultry appears to have the potential to improve poultry texture.

Postmortem electrical stimulation of lamb, pork, and beef carcasses has been shown to induce tenderness and has been used commercially (Carse, 1973; Grusby et al., 1976; Savell et al., 1977, 1978a, 1978b; Smith et al., 1977; Bouton et al., 1978). Researchers have noted other effects of electrical stimulation in beef, lamb, and pork. Consistently, electrical stimulation has induced an increase in the rates of pH decline and onset of rigor (Carse, 1973; Bendall et al., 1976; Grusby et al., 1976; Shaw and Walker, 1977; George et al., 1980) and an increase in the rates of ATP depletion and lactic acid accumulation (Bendall et al., 1976). One tenderizing mechanism which was suggested from these observations was that electrical stimulation reduced the effects of cold shortening by reducing conditioning time (Carse, 1973; Bendall et al., 1976; Chrystall and Hagyard, 1976). Locker and Hagyard (1963) showed that cold shortening did not occur to a significant extent below a muscle pH of 6; thus electrical stimulation hastened the time at which rapid, low temperature cooling ($< 2^{\circ}\text{C}$) or freezing could occur.

Changes in the structural characteristics of electrically stimulated meat, such as physical disruption of myofibrils or

sarcomere length, have been examined as possible factors contributing to the tenderizing effect of electrical stimulation (Savell et al., 1977, 1978a; Smith et al., 1977; Bouton et al., 1978, 1980, 1984; George et al., 1980). In electrically stimulated beef, lamb, and goat carcasses, sarcomere length seemed to be unrelated to the tenderness since there were no significant differences in sarcomere length between stimulated and nonstimulated samples (Savell et al., 1977; Smith et al., 1977; Salm et al., 1981; 1983). Other studies, however, have shown conflicting or inconsistent results, with stimulated sides having longer sarcomeres than controls (Bouton et al., 1978, 1980; George et al., 1980). Bouton et al. (1984) clarified the conflicting data by demonstrating that the mechanism of electrical stimulation tenderization was related to the temperature at which rigor occurred. At rigor temperatures $< 15^{\circ}\text{C}$ electrical stimulation seemed to reduce myofibrillar shortening, while at rigor temperature $\geq 15^{\circ}\text{C}$ electrical stimulation tenderization seemed unrelated to myofibrillar shortening having an effect more similar to aging.

Savell et al. (1978a) noted several structural changes other than sarcomere length that could have been responsible for the tenderizing effect of electrical stimulation. Electrically stimulated samples had contracture bands that displayed ill-defined I-bands and Z-lines. Additionally, the sarcomeres adjacent to the contracture bands appeared to be broken or stretched in some cases. The physical damage was theorized to lead to less structural integrity and to be at least a partial contributor to the improvement in tenderness.

Sorinmade et al. (1982) also found many changes in the ultrastructure of electrically stimulated meat. Light and electron micrographs revealed Longissimus muscle from electrically stimulated sides examined 48 hr postmortem had superstretched myofibrils with tearing around the Z-lines, and highly contracted myofibrils characterized by ill-defined or narrow I-bands, no H-bands, and indistinct A-bands. Approximately 30% of the tissue appeared to be damaged, and the damage observed in this study appeared to be greater than the damage observed in Savell's study in which the meat was examined 24 hr postmortem. Sorinmade et al. (1982) suggested that the difference was due to prolonged exposure to proteolytic enzymes released from ruptured lysosomes upon exposure to a rapid decline in pH at high temperatures. These workers also noted empty lysosomal vesicles and fragmentation of myofibrils at the Z-lines. Tenderization achieved by electrical stimulation, they concluded, appeared to be a result of physical disruption of myofibrils and possibly proteolysis.

In contrast, George et al. (1980) noted no myofibrillar damage resulting from electrical stimulation upon histological examination of meat aged for 48 hrs, but did find irregular bands of denatured sarcoplasmic protein deposited on the myofibril surface in the fibers of stimulated muscle that were similar to those found in pale soft exudative pork. No significance was attached to this observation in relationship to improved tenderness. Salm et al. (1981) observed similar results upon examining the fragmentation index of electrically

stimulated and nonstimulated carcasses, finding no difference between the two.

Smith et al. (1977) suggested that because the tenderizing effect of electrical stimulation did not seem to be related exclusively to a reduction in cold shortening or sarcomere length, a plausible cause of tenderization was related to autolytic enzyme activity. The rapid decrease in pH caused by electrical stimulation might rupture lysosomal membranes releasing proteolytic enzymes, which are active under conditions of high muscle temperature. Similarly, Salm et al. (1983) found that electrical stimulation enhanced the degradation of the myofibrillar proteins, actinin and troponin-T, and caused an increase in the amount of a 30,000 dalton protein, evidence of degradation of a myofibrillar protein.

Bouton et al. (1978) examined the possibility that some of the tenderizing effect was related to changes in connective tissue structure rather than myofibrillar structure. Using Instron compression (IC) values, which are relatively sensitive to connective tissue toughness, Bouton et al. (1978) found no significant differences in IC values in stimulated and nonstimulated meat after myofibrillar contribution to shear strength was removed by a pressure-heat treatment.

Effects of Electrical Stimulation on Palatability and Appearance

As well as affecting the texture of meat, electrical stimulation has been shown to change some aspects of the sensory profiles of meat. Savell et al. (1977, 1978b), Salm et al. (1981), and Hawrysh

and Wolfe (1983) reported no differences in flavor between stimulated and nonstimulated beef or lamb carcasses, but conflicting results were reported by Savell et al. (1977, 1978a), who found that Longissimus muscle from electrically stimulated beef sides was rated more flavorful by a 10-member taste panel than muscle from nonstimulated sides. Palatability tests conducted on steaks aged for 1 day showed heightened flavor desirability for those originating from electrically stimulated carcasses as opposed to nonstimulated (Savell et al., 1981; McKeith et al., 1982), but any flavor differences were negated by longer aging periods (Savell et al., 1981). Conducting taste panels after a 7 day aging period, Calkins et al. (1982) found no difference in flavor desirability, flavor intensity, or presence of off-flavors between steaks from electrically stimulated and nonstimulated beef sides.

Calkins et al. (1982) did find, however, that inosine and inosine monophosphate (IMP) levels at 12-24 hrs were higher in electrically stimulated than in nonstimulated samples, but after a 7 day aging period there were no significant differences in inosine or IMP levels suggesting that fluctuations in these two compounds followed a similar pattern to results from other studies regarding flavor changes in that these compounds are factors contributing to flavor differences in non-aged stimulated meat. Changes in ATP, adenosine diphosphate (ADP), adenosine monophosphate (AMP), and creatine phosphate (CP) levels appeared to have no contributing effect on the noted flavor differences.

Decreased juiciness in electrically stimulated carcasses as opposed to nonstimulated ones has been reported in beef frozen for 7-21 days (Savell et al., 1978a, 1978b), but this is not a consistent observation throughout the literature. Savell et al. (1977), Bouton et al. (1980), Salm et al. (1981), and Salm et al. (1983) found no significant difference in the juiciness of stimulated and nonstimulated beef or lamb carcasses. In the latter three studies there were no significant differences in cookloss, but there were significantly greater cooklosses in the electrically stimulated carcasses in the first two studies mentioned.

Electrical stimulation has also been shown to affect the color of meat. Grusby et al. (1976) and Hawrysh and Wolfe (1983) noted no color differences in Longissimus muscle removed from stimulated and nonstimulated carcasses cooler aged for 48 hrs to 7 days. Smith et al. (1977) reported similar observations on carcasses evaluated after 3 days of aging, but color evaluation conducted only 23 hrs postmortem showed that electrically stimulated carcasses had brighter color and a lower occurrence of heat rings. Savell et al. (1978) and Salm et al. (1981) also found better USDA color and fewer heat rings in electrically stimulated sides evaluated 19-24 hours postmortem. McKeith et al. (1982) also found an improvement in lean color in veal carcasses evaluated 24 hrs postmortem. No deleterious color effects as a result of electrical stimulation have been reported.

A few studies have been conducted to determine if electrical stimulation has any affect on connective tissue as judged by trained taste panelists. Savell et al. (1977, 1978b) found that panelists

rated connective tissue from electrically stimulated sides softer and rated the meat as having less connective tissue for both beef and lamb carcasses. In agreement with the latter finding Hawrysh and Wolfe (1983) found that eight trained taste panelists could not detect any differences between the connective tissue softness of stimulated or nonstimulated Longissimus or Semitendinosus muscle evaluated 48 hrs and 7 days postmortem.

Electrical Stimulation Methodology

A wide variety of voltages, currents, waveforms, duration times, pulse lengths, and electrode types and placements have been used over the course of research in electrical stimulation of meats, and no one optimal methodology has evolved. The major stimulation variable researchers have alluded to has been the voltage at which stimulation occurs. Initially the use of high voltages was examined, with voltages ranging from 3600V on sheep (Chrystall and Hagyard, 1976) to 700V (Bendall et al., 1976; George et al., 1980), 440V (Savell et al., 1978a, 1978b), 320V (Grusby et al., 1976), and 250V (Carse, 1973) on beef.

High voltages, however, pose major safety problems in a processing facility and have been reported to cause extreme muscle contraction and carcass distortion resulting in broken vertebrae and vertebral joints, and muscle tearing in the back area (Bendall et al., 1976; Chrystall and Hagyard, 1976). Because of these problems, researchers have investigated the use of low voltage stimulation to induce a tenderizing effect.

Carse (1973) found that electrical stimulation of lamb carcasses with lower voltages (60-250V) caused significant tenderness improvements compared to the tenderness of nonstimulated carcasses, but he did find that the lower voltages resulted in a slower rate of pH decline that affected the times at which low temperature cooling and hot-boning could occur. Even lower voltages (120-20V) were used by Savell et al. (1977), Shaw and Walker (1977), Bouton et al. (1978), and Taylor and Marshall (1980). All found that low voltage electrical stimulation induced a significant tenderizing effect and accelerated the rate of decline of muscle pH. PH values from stimulated carcasses taken at 1, 4, and 24 hrs postmortem were all significantly lower than the corresponding unstimulated controls regardless of the voltage applied (with one exception at 24 hrs where the pH was the same). Different electrode types and placements have been used as well as different waveforms and stimulation time schemes, including stepwise voltage increases up to the desired peak voltage.

Authors utilizing low voltage stimulation generally have concluded that low voltage stimulation was as effective in inducing tenderness as higher voltages. Bouton et al. (1980) directly compared three different voltage systems involving the use of a high voltage (1100V), a low voltage (110V), and an extra low voltage (45V) to test the efficacy of tenderness induction. These workers found that all stimulation treatments significantly improved tenderness when compared to nonstimulated controls for muscle removed 22 hrs postmortem, but that the use of the high voltage system was more suitable for reducing cold shortening effects than the low voltage treatments. Stimulation

was found to increase the rate of pH decline, with higher voltages causing more rapid declines. Other important observations from this study were that the high voltage system allowed the use of the rail as a ground electrode while only one other contact electrode would have been needed, but with the two low voltage systems, two or more electrodes would need to be attached, one in the hind quarter and one in the forequarter.

In an attempt to elucidate the pathways of high (850V peak) and low voltage (45V peak) stimulation, Morton and Newbold (1982) used curare to inhibit the functional nervous system in anesthetized sheep. Electrical stimulation regardless of voltage was found to accelerate glycolysis in control (nonanesthetized, exsanguinated sheep) and anesthetized exsanguinated sheep, but curare injections prior to slaughter negated the effect low voltage stimulation had on glycolysis acceleration. The authors concluded that for low voltage stimulation to be effective in accelerating glycolysis, a functional nervous system is required, but that high voltages can exert their effect by directly depolarizing the cell membrane. It is essential, therefore, that low voltage stimulation occurs very soon after death for complete effectiveness.

In an effort to further define optimal stimulation conditions, Chrystall and Devine (1978) observed the effects of various voltages, frequencies, pulse shapes, polarities, and stimulation periods on the effectiveness of electrical stimulation. The researchers found that electrical stimulation hastened the onset of rigor in a two-stage process. The initial stage occurred during stimulation resulting in a

rapid and dramatic decrease in pH of .5 to .7 pH units. The second stage occurs upon cessation of stimulation causing a much slower rate of pH decline compared to the first stage. The pH decline in the second stage, however, is still twice as fast as the decline in nonstimulated muscle. At a constant voltage (200V) frequency had a sizable effect on the magnitude of the pH fall in the first stage. Frequencies of 5 to 16.6 pulses/sec caused the largest drop in pH during the stimulation period (.7 pH units). Pulse shapes on polarities seemed to have little effect on the rate of pH decline in either stage. In this study a stimulation duration of 120 sec, regardless of voltage, was more effective in inducing a more rapid pH decline than shorter stimulation periods.

CHAPTER III
PRELIMINARY STUDY:
EFFECTS OF LOW VOLTAGE ELECTRICAL STIMULATION AT
VARIOUS DURATIONS ON THE TEXTURE OF HOT-STRIPPED BROILER BREAST MEAT

Introduction

Harvesting cut-up or boned meat prior to evisceration (hot-boned) or immediately after chilling (chill-boned), as opposed to harvesting after a 4-6 hour aging period (age-boned), is more desirable for processors due to savings accrued through reduced labor, storage, and handling requirements. Hot-boning and chill-boning, however, have a detrimental effect on the texture of light and dark broiler meat (de Fremery and Pool, 1960; Klose et al., 1972; Lyon et al., 1973; Peterson, 1977; Stewart et al., 1984a; Lyon et al., 1985). Results from these studies have indicated that some treatment to induce tenderness is needed if hot-boning is to be adopted for use in the industry or if utilization of chill-boning is to be continued by the industry. One possible method of improving the texture of hot-boned and chill-boned poultry involves the use of electrical stimulation.

Postmortem electrical stimulation is a standard practice in beef and lamb processing today. This method has had a long history of experimentation but was not adopted until the 1970s by the New Zealand lamb industry as a means of avoiding cold and thaw shortening in lambs that were frozen immediately after slaughter for shipment overseas. The technique was later adopted by the beef industry as a means of

hastening rigor development, reducing cold shortening, allowing for hot-boning, reducing the occurrence of heat rings, and improving color and texture of meat (Pearson and Dutson, 1985).

No one optimal methodology of stimulation has evolved thus far. Many early studies utilized high voltages ranging from 3,600 to 250 volts. The use of high voltages, however, has posed major safety problems in a processing facility and caused extreme muscle contracture and carcass distortion resulting in broken joints and muscle tearing (Bendall et al., 1976; Chrystall and Hagyard, 1976). Because of these problems researchers have investigated the use of low voltage stimulation to induce a tenderness response.

Experimentation with low voltages (120 to 20 volts) resulted in significant tenderness improvements and increased rates of pH decline over nonstimulated carcasses, but higher stimulation voltages resulted in more rapid pH declines (Carse, 1973; Bouton et al., 1980). Bouton et al. (1980) concluded that low voltage stimulation (45 volts) was as effective as higher voltages in inducing tenderness, but higher voltages were more suitable in reducing the effects of cold shortening due to accelerated rates of glycolysis. In this same study workers found that using high voltages allowed for the use of the rail as the ground and only one other ground electrode. Low voltage systems, however, required the use of two or more contact electrodes to overcome the resistance of the carcass.

Morton and Newbold (1982) found that the use of low voltage stimulation had a limited effect on accelerating glycolysis if applied late in the processing scheme. Using anesthetized sheep and curare

injections, the authors found that low voltage stimulation required a functional nervous system to be effective, but high voltage stimulation exerted its effect by directly depolarizing the muscle cell membranes. It is generally recommended that low voltage stimulation be applied within 10 minutes after death for complete effectiveness (Savell, 1985).

At the time this preliminary study was undertaken little work had been published examining the effects of postmortem electrical stimulation on the texture of poultry meat. De Fremery and Pool (1960) removed the Pectoralis superficialis from six 11 week old chickens and stimulated one fillet from each carcasses for 30 minutes with voltage gradually increasing from 20 volts to 390 volts. The current was pulsed on for 0.1 second at 1 second intervals. The stimulated muscles had higher shear values (5.5 kg) than the nonstimulated controls (3.7 kg). In a second experiment these workers found that electrical stimulation of hot-stripped fillets with 90 volts increased the rates of ATP depletion and pH decline over the nonstimulated fillets.

The objectives of this experiment were to determine if low voltage stimulation for relatively short durations would improve the tenderness of hot-boned broiler breast meat. Because low voltage electrical stimulation was effective in inducing a tenderness response in beef, and because of the problems of carcass distortion and safety associated with high voltage stimulation, a relatively low voltage of 45 volts was selected for this preliminary experiment examining the effects of postmortem electrical stimulation on the tenderness of

hot-boned broiler breast meat. Since electrical stimulation of excised breast fillets caused increased toughness in the breast meat, (de Fremery and Pool, 1960) whole carcasses were stimulated. The stimulation was applied immediately after exsanguination, since Morton and Newbold (1982) concluded that a functional nervous system was a prerequisite for the effective use of low voltage stimulation.

Materials and Methods

Processing Scheme

Male Cobb, feather-sexed broilers, 49 days of age, reared on a commercial-type broiler diet were fasted for 12 hours, and then cooped 8/coop for a total of 36 birds. Six birds per replication were hung by the shanks on shackles, individually identified by duplicate wing bands, and electrically stunned using a Cervin model FS stunner on setting 4 and killed by exsanguination. Following a 90 second bleeding period, the carcasses were subjected to the stimulation treatments using a Koch low voltage electrical stimulator (45 volts). Two carcasses per replication were electrically stimulated for 0, 9, and 18 seconds by placing an electrode around the neck while the rail/shackle system functioned as the ground. The feathers were removed by subscalding the carcasses in an Ashley scalding tank at 60°C for 45 seconds and picking in a commercial rotary drum picker for 25 seconds.

Following feather removal, the carcasses were hot-boned. Carcasses were suspended from the shackle by the neck; after removal of the skin from the breast, the humeral-scapular joint was severed

and the Pectoralis superficialis muscles with the wings attached were stripped from the carcass by firmly pulling downward on the wings.

The fillets were chilled in ice slush for one hour, allowed to drain for 10 minutes, and ice packed. Following a 24-hour holding period at 2°C, paired fillets were bagged together and held at -23°C, for 12 days for subsequent cooking and shear evaluation.

Cooking Procedure

Paired fillets with the wings attached were cooked by replication on roasting racks in foil-lined and covered stainless steel pans, in a rotary hearth oven at 177°C to an internal temperature of 82°C. Internal temperature was monitored using copper constant thermocouples placed in the thickest portion of the breast. Cooked fillets were cooled to room temperature, wrapped by replication in aluminium foil, and held overnight at 7°C for shear force evaluation.

Shear Force Evaluation

Duplicate samples (1 x 1 x 2-3 cm) were obtained from the anterior portion of each fillet, with the long dimension paralleling muscle fibers. Samples were sheared perpendicular to the muscle fibers in a standard 10-blade shear compression cell. A Food Technology Corporation Texture Test System shear instrument, equipped with a 136 kg force transducer and a TG-4A Texturegage, was used with a descent speed of 0.7 cm/sec. Data were converted to kg force/g sample and the four shear values from each carcass were averaged.

Statistical Analysis

Means for each treatment were calculated along with standard error of the means (Steel and Torrie, 1960).

Results and Discussion

The mean shear value of breast meat obtained from nonstimulated carcasses was similar to values previously reported by Sams (1984) and was higher than the shear values observed for the breast meat from the stimulated carcasses (Table 3-1). Low voltage stimulation of carcasses, however, did not reduce shear values to an acceptable tenderness level below the 8 kg force/g sample suggested by Simpson and Goodwin (1974). It is possible that stimulation with higher voltages and/or longer stimulation durations might cause even greater improvements in tenderness since higher voltages have been shown to be more effective in hastening rigor thus avoiding toughening associated with hot-boning (Bouton et al., 1980).

The lack of a more pronounced tenderizing effect with 45V may have resulted because the nervous system of poultry is rendered nonfunctional within minutes after death. Morton and Newbold (1982) observed in sheep that high voltage stimulation directly depolarizing the sarcolemma causing muscle contraction, but low voltage stimulation depolarized the nervous system causing the nervous system to initiate muscle contraction, not the externally applied voltage. If the functional capabilities of the nervous system are impaired prior to or during stimulation the effectiveness of the low voltage stimulation treatment would be reduced.

Table 3-1. Mean shear values \pm standard error of the means of hot-boned broiler breast meat obtained from carcasses stimulated with 45 volts for 0, 9, or 18 seconds

	Stimulation duration (sec.)		
	0	9	18
Shear value	11.9 \pm 0.74	9.2 \pm 0.64	9.2 \pm 0.65

Conclusions

Results from this experiment indicated that low voltage stimulation caused a slight improvement in the tenderness of hot-boned broiler breast meat with the stimulation durations utilized. Subsequent experiments need to focus on the use of higher voltages and various stimulation durations. Additionally, biochemical and physical parameters, such as ATP levels, pH, sarcomere lengths, and myofibril fragmentation should be examined in order to determine a clearer picture of the effects of electrical stimulation on the poultry meat.

CHAPTER IV
EFFECTS OF ELECTRICAL STIMULATION AT VARIOUS DURATIONS
ON THE TEXTURE OF BROILER BREAST MEAT

Introduction

Data from the preliminary study, discussed in Chapter III, demonstrated that low voltage (45V) postmortem electrical stimulation caused a slight improvement in the tenderness of hot-boned broiler breast meat. Bouton et al. (1980), however, found that high voltage stimulation of beef was more effective in reducing the effects of hot-boning than was low voltage stimulation. Maki and Froning (1984) observed that stimulating turkeys with 800 volts improved the tenderness of aged turkey breast meat.

The use of high voltage, however, has been associated with muscle tearing, and broken and disjointed bones in beef carcasses (Bendall et al., 1976; Chrystall and Hagyard, 1976). Broken and disjointed bones and torn muscles could result in lowered U.S.D.A. grades in broiler carcasses and parts, detract from the overall product appearance, and ultimately cause economic losses. A medium range stimulation voltage (240V) was chosen for use in the second experiment, possibly avoiding broken bones, disjoints and muscle damage associated with higher voltages.

The purpose of this experiment was to determine if electrical stimulation with medium voltage improves the texture of hot-boned, chill-boned, or age-boned broiler breast meat and to determine an

optimal stimulation duration at a given voltage in order to achieve a maximum tenderness response.

Materials and Methods

Two trials were conducted utilizing a stimulation voltage of 240V. Three of 12 carcasses per replication (5 replicates/trial) were subjected to one of four stimulation durations: 0, 15, 30, and 45 seconds. One carcass from each stimulation treatment was either hot-boned, chill-boned, or age-boned.

Basic Processing, Electrical Stimulation, and Boning

On two separate days (2 trials), 52 and 53 day-old male Cobb, feather-sexed, broilers reared on a commercial type broiler diet were weighed to obtain a uniform weight range, fasted for 9 hours, and cooped 10/coop for a total of 120 birds (60/trial). Twelve birds per replication were hung by the shanks on shackles, individually identified with duplicate wing bands, and electrically stunned using a Cervin model FS stunner set on setting 4, and killed by exsanguination. Following a 90 second bleeding period, the carcasses were subjected to the stimulation treatments using the same Cervin Stunner on the highest setting producing 340 ma and equipped with a rheostat to produce a constant voltage of 240V. The carcasses were electrically stimulated by using the shackle/rail system as the ground and placing the kill knife on the skin at the back of the neck near the last cervical vertebra, and pulsing the current on for 2 seconds and off for 1 second, as typically practiced in the beef industry (Savell, 1985), until the total time of 15, 30, or 45 seconds had

elapsed. Stimulation caused pronounced muscle contraction with the maximum initially observed response declining after 12-15 seconds of stimulation. Generally by the end of a 45 second stimulation period the degree of response was minimal with only slight visual evidence of muscle contraction.

After electrical stimulation the feathers were removed by subscalding the carcasses in an Ashley scaldler at 60°C for 45 seconds and picking in a commercial rotary drum picker for 25 seconds.

Following feather removal, one carcass from each stimulation treatment (4 total carcasses/rep) was hot-boned. Carcasses were suspended from the shackle by the neck; after removing the skin from the breast, the humeral-scapular joint was severed and both Pectoralis superficialis muscles with the wings attached were stripped from the carcass by firmly pulling downward on the wings. The left Pectoralis superficialis was weighed and chilled. The right Pectoralis superficialis was immediately divided into sections and frozen in liquid nitrogen for pH and R-value analysis. Due to insufficient liquid nitrogen storage facilities, samples for fragmentation index and sarcomere length analysis were stored at -23°C, conditions similar to those used by Culler et al. (1978) and Calkins et al. (1980). Concurrently, the remaining 8 carcasses were eviscerated using standard procedures, rinsed, and weighed.

Carcasses and hot-boned fillets were immersion chilled separately, in tap water using a two stage process to simulate commercial time-temperature conditions (15 minutes at 21°C, followed by 30 minutes in 1°C ice-slush). A 3:1 water to carcass or fillet

ratio was maintained (Mickelberry et al., 1962), and to improve the cooling rate, carcasses/fillets were agitated in the chilling medium by moving wire baskets containing carcasses or fillets up and down.

Carcasses/fillets were hung by the wings, rinsed, and drained for 5 minutes prior to weighing to determine percent water uptake. Both Pectoralis superficialis muscles from one carcass from each stimulation treatment (4 carcasses/rep) were removed and sampled as described for hot-boned fillet harvesting and sampling. The hot- and chill-boned fillets, and the remaining intact carcasses (4 carcasses/rep) were packed in ice, and held for 48 hours at 2°C prior to weighing for determination of percent driploss. Remaining intact aged carcasses (one/stimulation treatment) were boned and sampled as previously described.

Cooking Procedure and Percent Cookloss

Wings were removed from all left-side fillets: new identification bands were attached and fillets were weighed. Fillets were cooked, by replication, on roasting racks in foil-lined and covered stainless steel pans in a rotary hearth oven at 177°C to an internal temperature of 82°C. Internal temperature was monitored using copper constantan thermocouples equipped with a digital display and placed in the thickest portion of the breast. Cooked fillets were cooled to room temperature (25°C), reweighed to determine percent cookloss, wrapped in foil, and held overnight at 7°C for shear force evaluation.

Shear Force and Cooked Moisture

Duplicate samples (1 x 1 x 2-3 cm) were obtained from the anterior portion of each fillet with the long dimension paralleling muscle fibers. Samples were sheared perpendicular to the direction of the muscle fibers in a standard 10-blade shear compression cell. A Food Technology Corporation Texture Test System shear instrument, equipped with a 136 kg force transducer and at TG-4A Texturegagage was used with a descent speed of 0.7 cm/sec. Data were converted to kg force/g sample and averaged for each fillet. Meat from each fillet was chopped, packaged in Whirl-pak bags, and held at -23°C for 2-3 weeks for moisture evaluation (AOAC, 1970). Moisture evaluation, as well as percent cookloss, water uptake and driploss were determined to detect possible changes in the water-holding capacity of the meat, which could effect the functional properties or tenderness of the meat. Additionally, percent water uptake and droploss were monitored to determine if electrical stimulation caused problems regarding compliance with U.S.D.A. chilling regulations. The U.S.D.A. regulations allow a maximum 8% water uptake in ice-packed broilers sent directly to nearby consumer markets, or 12% if shipped and rehandled in distant markets (Brant et al., 1982).

PH Determination

Liquid nitrogen frozen samples (4-5 g) obtained from the caudal end of the right-side fillets at the time of boning were removed from liquid nitrogen, wrapped in butcher paper, and pulverized with a hammer. A 1:10 (w/v) solution of meat powder and approximately 7°C 0.005 M sodium iodoacetate were blended in a 100 ml stainless steel

cup at medium-high speed (approximately 14,600 rpm) using a Virtis 23 homogenizer for 30 seconds prior to solution pH determination using a Corning Model 125 pH equipped with a Fisher combination, protected polymer body, gel filled pH electrode (Sams, 1984).

R-Value

R-values were determined using procedures described by Khan and Frey (1971) and Honikel and Fischer (1977) on liquid nitrogen frozen samples (3-4 g) from each right-side fillet. Approximately 3 g of the meat powder, obtained as described for the pH samples, was homogenized in 20 ml of 1 M perchloric acid for 1 minute using a Virtis 23 homogenizer at 14,600 rpm. After gravity filtration (Fisher P8 filter paper), 0.1 ml of the acid filtrate was added to 4 ml of 0.1 M phosphate buffer. Absorbances at 250 and 260 nm were obtained using a Hitachi Perkin-Elmer spectrophotometer at a slit width of 0.5 nm, and R-values or absorbance ratios for each sample were calculated as A_{250}/A_{260} .

Sacromere Length

Frozen samples (10-15 g) from the medial area of each right-side fillet were cubed and homogenized in 25 ml of cold 0.25 M sucrose using a Virtis 23 homogenizer at 11,500 rpm for 10-15 seconds until fiber separation was noted. Two drops of the homogenate were placed on a microscopic slide, covered with a cover slip, and placed in the path of a helium-neon laser (wavelength = 632.8 nm). The sacromere length was determined using methods and the equation described by Cross et al. (1980).

Fragmentation Index

The fragmentation index (FI) was determined by adapting procedures used for beef as outlined by Calkins and Davis (1978) and Davis et al. (1980). In a preliminary study using the method outlined by Davis et al. (1980), few differences in fragmentation index were found in broiler breast meat with shear values ranging from 3.5 to 18.0 kg force/g sample. The homogenization treatment outlined for use with beef was too severe for poultry meat, and as a result the majority of the homogenate passed through the 250 μm filter screen. In subsequent preliminary trials the length of the homogenization period and speed (rpms) were varied using a Virtis homogenizer or a Waring blender. In some trials a larger screen size, 500 μm , was used instead of the 250 μm screen suggested by Davis et al. (1980). Eventually, a procedure utilizing the 250 μm screen and a Waring blender produced fragmentation indexes that were related to the shear values of broiler breast meat.

To determine fragmentation index, frozen samples (5-6 g) obtained at the time of boning from the anterior portion of each right-side fillet were chopped into 5 mm cubes, weighed to the nearest 0.0001 g, and homogenized with 50 ml of 0.25 M sucrose, 0.02 M KCl solution at high speed for 30 seconds with a Waring blender. The homogenate was vacuum filtered through a tared 250 μm nylon screen to approximately the same dryness. After air drying for ten minutes on Fisher P8 filter paper, the weight of residue was determined and fragmentation index was calculated using the following formula:

$$\text{FI} = 1000 \times (\text{Residue weight}/\text{Original sample weight}).$$

Statistical Analysis

Data within each boning treatment were analyzed using analyses of variance, Duncan's Multiple Range test, and, where appropriate, orthogonal comparisons (Steel and Torrie, 1960) utilizing the General Linear Model system available in the Statistical Analysis Systems package (SAS, 1982). Shear force, pH, R-value, sarcomere length, and fragmentation index data were tested for correlations over the entire experiment, within boning treatments, and within boning-stimulation treatments using programs available in SAS, and standard error of the means were calculated for each boning-stimulation treatment (SAS, 1982). Data from both trials were combined since there were no significant trial x treatment interactions.

Results and Discussion

Data in Table 4-1 reflect shear values, pH, R-values, sarcomere lengths, and fragmentation indexes of the nonstimulated control samples for each boning treatment, demonstrating the relationships between the three boning treatments for each of the parameters. It was not the major focus of the research to examine the tenderness differences between the various boning treatments for they have been previously documented (Sams, 1984), but to examine the effects of electrical stimulation on tenderness within a boning treatment. These data established reference values for the various parameters, in order to determine the effects of electrical stimulation, particularly for those parameters for which little published data pertaining to poultry meat exists. These data will be used to briefly review the physical

Table 4-1. Shear values, pH, R-values, sarcomere lengths, and fragmentation indexes of hot-boned, chill-boned, and age-boned broiler breast meat obtained from nonstimulated (control) carcasses

Boning treatment	Shear value (kg force/ g sample)	pH	R-value*	Sarcomere length (μm)	Fragmentation** index
Hot-boned	15.7 \pm 1.38***	6.08 \pm 0.04	0.92 \pm 0.03	1.63 \pm 0.03	404 \pm 47
Chill-boned	9.9 \pm 1.83	6.00 \pm 0.07	1.02 \pm 0.05	1.60 \pm 0.05	385 \pm 45
Age-boned	4.2 \pm 0.63	5.71 \pm 0.06	1.37 \pm 0.01	1.79 \pm 0.04	255 \pm 66

* R-value = absorbance 250 nm/absorbance 260 nm of an acid extract of muscle tissue.

** Fragmentation index = 1000 x (residue wt./sample wt.).

*** Means \pm standard error of the mean.

and biochemical differences between the boning treatments and to discuss some postmortem changes that occur as muscle is converted to meat.

Harvesting of broiler breast fillets immediately after picking (hot-boned) or immediately after chilling (chill-boned) caused a dramatic increase in toughness, and increased variations associated mean shear values compared to harvesting after a 48-hour aging period (age-boned) (Table 4-1), a trend that has been well documented in the literature (Sams, 1984; Stewart et al., 1984a; Lyon et al., 1985; Dawson et al., 1986). According to Simpson and Goodwin (1974) poultry meat with a shear value of 8 kg force/g sample or above is unacceptably tough. Hot-boned and chill-boned fillets produced unacceptably tough products with shear values above 15 and 9 kg force/g sample, respectively.

As the time between slaughter and boning increased there was a corresponding decrease in muscle pH and an increase in R-values (Table 4-1). The increasing R-values with delayed boning reflected postmortem changes that occurred primarily in the ratio of IMP to ATP. The R-value is an indicator of the relative amounts of IMP, inosine, and hypoxanthine to adenine nucleotides, as detected by absorbance of an acid extract of muscle tissue at 250 nm/260nm, respectively, and is not an absolute quantification of IMP and ATP levels. Adenine diphosphate, AMP, inosine, and hypoxanthine are present in much smaller concentrations than ATP and IMP and have only a small effect on the R-value of meat. A pure ATP solution had an absorbance ratio of approximately 0.80, and a pure IMP preparation had

a ratio of approximately 1.70. Calkins et al. (1982) reported that the R-value (A250/A260) of aged beef was 1.35, similar to the value reported in Table 4-1 for age-boned breast meat.

After death during rigor development, muscle cells attempt to maintain antemortem ATP levels, but ATP is rapidly depleted because cells rapidly lose the ability to regenerate ATP due to the dysfunction of the mitochondria under the anaerobic conditions that develop as a result of the loss of the circulatory system. Some ATP is generated by conversion of CP and ADP to ATP. Creatine phosphate is rapidly used up and ATP is produced through anaerobic glycolysis which results in the accumulation of lactic acid in the tissues and the typical decrease in postmortem muscle pH seen in Table 4-1. As muscle progress through normal postmortem rigor development, ATP is depleted resulting in the formation of AMP. Adenosine monophosphate is deaminated forming IMP, thus as rigor progresses ATP levels decrease while IMP levels increase. Eventually IMP is dephosphorylated forming inosine and inosine is hydrolyzed forming hypoxanthine (Hultin, 1976). Over the course of rigor development, as mentioned across the three boning treatments, pH was positively and significantly ($P < 0.01$) correlated to shear values, and R-values were negatively and significantly ($P < 0.01$) correlated to shear values with correlation coefficients of 0.37 and -0.65, respectively, agreeing with data published by Khan and Frey (1971).

Khan and Frey (1971) reported that monitoring the postmortem change in the ratio of IMP/ATP spectrophotometrically was useful in determining the state of rigor mortis. They found that changes in the

R-value over time corresponded to the development of rigor mortis, with R-values increasing as rigor developed and leveling off at a maximum once maximum rigor contraction occurred.

Khan and Frey (1971) reported that the ultimate pH and R-value of poultry muscle was achieved within 24 and 48 hours, respectively. Since age-boning occurred 48 hours postmortem, the pH and R-values obtained in this experiment (Table 4-1) reflected the ultimate levels achieved in typically processed meat and were similar to pH values reported by Stewart et al. (1984a) in poultry and R-values reported by Honikel and Fisher (1977) in beef.

As the time of boning increased, the sarcomere lengths increased, which corresponded to decreases in shear values. Additionally, sarcomere lengths were negatively and significantly correlated to shear values when data from all three boning treatments were analyzed ($P < 0.01$, $r = -0.50$). The degree of muscle contraction or muscle shortening has been shown to be one factor relating to the tenderness of meat (Marsh and Leet, 1966), and sarcomere lengths have been used as a simple means of estimating the degree of contraction (Howard and Judge, 1968). Herring et al. (1967) reported a negative and curvilinear relationship between shear values and sarcomere lengths in beef muscle. In their study, sarcomere lengths of approximately 1.6 μm corresponded to high shear values between 18-14 kg force/g sample, and longer sarcomere lengths (2.0 μm) corresponded to considerably lower shear values, as found in the data in Table 4-1.

Increased muscle shortening with the boning of prerigor meat, as seen in hot-boned and chill-boned fillets (Table 4-1), has been

attributed to the release of physical anatomical restraints prior to rigor, allowing for unimpeded muscle contraction resulting in increased shortening during rigor development (Kastner et al., 1973; Falk et al., 1975).

Janky et al. (1983) reported sarcomere lengths for aged carcasses of approximately 2.0 μm , while values in this study were somewhat shorter (1.8 μm). These differences might have been due to the use of different methods to determine the sarcomere lengths. Janky et al. (1983) utilized an oil immersion microscopic method while the laser diffraction method was utilized in this study. Cross et al. (1980) reported that the laser diffraction method measured many more sarcomeres than the oil immersion method, allowing for a more representative average than that found using the microscopic technique, which could account for the differences observed between the two experiments.

Myofibril fragmentation is another factor that has been found to be related to the tenderness of meat. Myofibril fragmentation has been used as an indication of structural weakening of myofibrils generally believed to be associated with structural changes occurring at or near the Z-lines (Davey and Gilbert, 1969; Sayre, 1970), a loss of adhesion between adjacent myofibrils, and a general loss of tensile strength in the myofibrils (Davey and Gilbert, 1969), possibly caused by myofibrillar protein hydrolysis with endogenous lysosomal enzymes (Hultin, 1976). Fragmentability of myofibrils has been related to the tenderness of poultry (Sayre, 1970), and beef (Culler et al., 1978), with tougher meat having a greater resistance to fragmentation. As

the time of boning increased, the muscles had lower fragmentation indexes (increased fragmentability) which corresponded to decreased shear values (Table 4-1). Across the three boning treatments, fragmentation indexes and shear values were significantly and positively correlated ($P < 0.01$, $r = 0.63$). Culler et al. (1978) reported that fragmentation index accounted for a maximum of 50% of the variability in the tenderness of loin steaks and that it appeared to be a more important factor in the tenderness of aged meat than sarcomere lengths.

Postmortem electrical stimulation of carcasses with 240 volts for intervals to 45 seconds did not improve the tenderness of hot-boned fillets (Table 4-2). Postmortem electrical stimulation of beef has been shown to offset the undesirable increase in toughness caused by hot-boning even when meat was boned as early as 1 hour postmortem (Cross and Tennent, 1980). Dransfield et al. (1985), however, found that postmortem electrical stimulation of turkeys did not improve tenderness, as typically found in beef.

The pH at the time of hot-boning was not significantly affected by electrical stimulation with all pH values above 6 (Table 4-2). Numerous workers have reported that electrical stimulation increases the rate of pH decline in beef and lamb muscles producing lowered pH over that observed for nonstimulated controls (Carse, 1973; Chrystall and Devine, 1978). After death, during rigor development, muscle cells attempt to maintain antemortem ATP levels using aerobic mechanisms and by converting CP and ADP to ATP, but eventually ATP is produced through anaerobic glycolysis which results in the

Table 4-2. Mean shear values, pH, R-values, sarcomere lengths, and fragmentation indexes \pm standard error of the mean of hot-boned broiler breast meat obtained from carcasses stimulated with 240 volts for 0, 15, 30, or 45 seconds

Stimulation duration (sec.)	Shear value (kg force/g sample)	pH	R-value*	Sarcomere length (μ m)	Fragmentation** index
0	15.7 ^a \pm 1.38***	6.08 ^a \pm 0.04	0.92 ^a \pm 0.03	1.63 ^a \pm 0.03	404 ^a \pm 47
15	15.2 ^a \pm 1.61	6.11 ^a \pm 0.04	0.98 ^{ab} \pm 0.02	1.62 ^a \pm 0.05	502 ^a \pm 67
30	15.7 ^a \pm 1.69	6.07 ^a \pm 0.05	1.03 ^b \pm 0.02	1.53 ^a \pm 0.06	511 ^a \pm 66
45	15.2 ^a \pm 1.37	6.06 ^a \pm 0.05	1.02 ^b \pm 0.04	1.59 ^a \pm 0.01	526 ^a \pm 77

* R-value = absorbance 250 nm/absorbance 260 nm of an acid extract of muscle tissue.

** Fragmentation index = 1000 x (residue wt./sample wt.).

*** Means within a column with different superscripts are significantly different (P<0.05).

accumulation of lactic acid in the muscle tissues and a typical decrease in postmortem muscle pH (Hultin, 1976). Electrical stimulation hastens these processes by causing muscle contraction, thus a more rapid depletion of ATP, CP, and accumulation of lactic acid compared to nonstimulated muscle. In the present study, however, hot-boning occurred within 10 minutes of electrical stimulation so it is possible that muscle from stimulated carcasses had not accumulated significantly greater amounts of lactic acid than nonstimulated muscle, causing a lack of significant differences in pH between the treatments.

Electrical stimulation produced a significant increase in the R-value (Table 4-2) with the 30 and 45 second durations being more effective in increasing the rate of postmortem rigor development. As the meat progresses through normal postmortem rigor development, ATP is depleted resulting in the formation of AMP. Adenosine monophosphate is deaminated forming IMP, thus as rigor progresses, ATP levels decrease while IMP levels increase. Khan and Frey (1971) have reported that monitoring the postmortem change in the ratio of ATP/IMP spectrophotometrically was useful in determining the state of rigor. They found that changes in the R-values over time corresponded to the development of rigor mortis, with maximum rigor contraction occurring at the point of a stable and minimum R-value. From data in Table 4-2, it was evident that electrical stimulation increased the rate of rigor development compared to nonstimulated meat and that lengthening the duration of stimulation increased the rate of rigor development. The R-value appeared to be a much more sensitive indicator of the

progression of early postmortem rigor development than pH, since no significant differences in pH at the time of boning were observed, but significant differences were found in the R-values.

There were no significant differences in sarcomere lengths between any of the treatments (Table 4-2), which corresponded to a lack of significant differences in the shear values. Herring et al. (1967) reported a negative and curvilinear relationship between shear values and sarcomere lengths in beef muscle. Since no significant shear value differences existed it was not surprising that differences in sarcomere lengths were not found since the two were correlated in earlier studies.

Electrical stimulation treatment had no significant effect on the fragmentation index of hot-boned broiler breast meat (Table 4-2). Also, no significant differences were found when an orthogonal comparison between the stimulated and nonstimulated controls was conducted ($P < 0.89$). Fragmentability of myofibrils has been related to tenderness of poultry (Sayre, 1970) and beef (Culler et al., 1978), with tougher meat having a greater resistance to fragmentation. Since there were no significant differences in shear values between the treatments it is reasonable that no differences in fragmentation indexes were found.

The lack of a tenderness response in hot-boned, prerigor, breast meat obtained from electrically stimulated carcasses was well supported by observed data obtained for pH, sarcomere length, and fragmentation index, and could be due to several factors. Electrical stimulation has been used as a tool to induce more rapid onset of

rigor mortis thus allowing for hot-boning and rapid chilling. In this study, hot-boned fillets, from stimulated and nonstimulated carcasses, were removed from the carcasses prior to full rigor development as evidenced by the lack of muscle stiffness, and relatively high pH values and low R-values. Removing the prerigor meat from the bone released physical anatomical restraints allowing for unimpeded contraction while the meat is progressing into rigor. The act of hot-boning also provided the meat with a stimulus, inducing contraction to occur. The low values (1.6 μm) for sarcomere lengths reflected this increase in the degree of contraction, and shorter sarcomeres have been related to increased toughness (Herring et al., 1967).

Electrical stimulation probably failed to illicit a tenderness response since boning occurred so soon after stimulation and prior to full rigor development. Even though the rate of rigor development was increased by electrical stimulation, as reflected by larger R-values, rigor development was not complete, therefore, hot-boning still acted as a toughening agent. An orthogonal comparison between nonstimulated control and stimulated also revealed there were no significant differences ($P>0.89$). Analyzing data within the hot-boning treatment pH was significantly correlated with shear values ($r=-0.42$, $P<0.01$) and fragmentation indexes with pH ($r=-0.54$, $P<0.01$), indicating that tenderness of meat boned prior to rigor development is related to the pH at which boning occurs, and the fragmentability of the myofibrils is also related to pH.

Postmortem electrical stimulation of carcasses with 240 volts did not significantly improve the tenderness of broiler breast meat boned

immediately after chilling (chill-boned) (Table 4-3). Using the criteria established by Simpson and Goodwin (1974) the meat was still unacceptably tough but samples from carcasses stimulated for 15 and 45 seconds approached this critical point of 8.0 kg force/g sample.

The rate of rigor development was significantly affected by electrical stimulation as reflected in a significant increase in R-value and decrease in pH at the time of chill-boning (Table 4-3). The pH nor R-values were not significantly different for the nonstimulated and 15 second stimulated samples, but 30 seconds of stimulation produced a significant increase in the rate of rigor development.

Electrical stimulation did not significantly affect the sarcomere lengths or fragmentation indexes of the chill-boned meat, but there was a trend toward longer sarcomere lengths with stimulation as demonstrated in an orthogonal comparison of fillets from nonstimulated vs. stimulated carcasses ($P < 0.11$), which corresponds with the shear data (Table 4-3). Within the chill-boned treatment, sarcomere lengths and FI were significantly correlated with shear values ($r = -0.28$, $P < 0.08$; $r = 0.55$, $P < 0.01$). Additionally, sarcomere lengths and fragmentation indexes were correlated with both pH and R-values. This indicated that the tenderness of chill-boned fillets is related to the point of rigor development at which boning occurs, and that sarcomere lengths and fragmentation indexes both were valid indicators of tenderness, within the boning time.

Broiler breast meat deboned approximately 48 hours postmortem (age-boned), as expected, was very tender as indicated by the low shear values, and electrical stimulation did not significantly

Table 4-3. Mean shear values, pH, R-values, sarcomere lengths, and fragmentation indexes \pm standard error of the mean of chill-boned broiler breast meat obtained from carcasses stimulated with 240 volts for 0, 15, 30, or 45 seconds

Stimulation duration (sec.)	Shear value (kg force/g sample)	pH	R-value*	Sarcomere length (μ m)	Fragmentation** index
0	9.9 ^a \pm 1.83***	6.00 ^a \pm 0.07	1.02 ^a \pm 0.05	1.60 ^a \pm 0.05	385 ^a \pm 45
15	8.2 ^a \pm 1.06	5.94 ^{ab} \pm 0.05	1.12 ^{ab} \pm 0.03	1.63 ^a \pm 0.03	389 ^a \pm 49
30	9.0 ^a \pm 1.51	5.83 ^b \pm 0.05	1.18 ^b \pm 0.04	1.70 ^a \pm 0.04	372 ^a \pm 50
45	8.3 ^a \pm 1.28	5.89 ^b \pm 0.07	1.22 ^b \pm 0.02	1.71 ^a \pm 0.05	346 ^a \pm 38

* R-value = absorbance 250 nm/absorbance 260 nm of an acid extract of muscle tissue.

** Fragmentation index = 1000 x (residue wt./sample wt.).

*** Means within a column with different superscripts are significantly different (P<0.05).

increase tenderness regardless of the stimulation duration (Table 4-4). In agreement with these findings, there were also no significant differences in the fragmentation indexes or sarcomere lengths between any of the treatments.

Electrical stimulation did not produce any significant differences in the pH, or R-values of age-boned meat regardless of the duration of stimulation (Table 4-4). Khan and Frey reported that pH and R-values reached their ultimate levels within 24 and 48 hours postmortem, respectively. Since the age-boned fillets were aged for 48 hours prior to boning and sampling, no differences in pH or R-values would be expected because the ultimate pH and ATP concentrations would have already been achieved. Electrical stimulation increased the rate of rigor development, but electrical stimulation does not alter the ultimate pH (Pearson and Dutson, 1985), or the ultimate concentration of ATP, ADP, AMP, CP, IMP, or inosine (Calkins et al., 1982) of meat.

Electrical stimulation had no significant effect on the water holding capacity (WHC) of hot-boned, chill-boned or age-boned meat as reflected in the percent water uptake, driploss, cookloss, cooked moisture of the meat (Table 4-5). Whiting et al. (1981) and Terrell et al. (1981) found that electrical stimulation had no significant effect on the WHC of lamb or beef, respectively. The values obtained in this experiment for water uptake and driploss were somewhat higher than values previously reported (Sams, 1984), but the differences could be accounted for by the use of slightly different agitation techniques during chilling. The differences in water uptake,

Table 4-4. Mean shear values, pH, R-values, sarcomere lengths, and fragmentation indexes \pm standard error of the mean of age-boned broiler breast meat obtained from carcasses stimulated with 240 volts for 0, 15, 30, or 45 seconds

Stimulation duration (sec.)	Shear value (kg force/g sample)	pH	R-value*	Sarcomere length (μ m)	Fragmentation** index
0	4.2 ^a \pm 0.63***	5.71 ^a \pm 0.06	1.37 ^a \pm 0.01	1.79 ^a \pm 0.04	255 ^a \pm 66
15	3.8 ^a \pm 0.38	5.72 ^a \pm 0.06	1.39 ^a \pm 0.01	1.78 ^a \pm 0.03	245 ^a \pm 38
30	4.0 ^a \pm 0.44	5.67 ^a \pm 0.05	1.40 ^a \pm 0.02	1.84 ^a \pm 0.06	213 ^a \pm 19
45	3.7 ^a \pm 1.10	5.68 ^a \pm 0.05	1.40 ^a \pm 0.02	1.83 ^a \pm 0.05	279 ^a \pm 42

* R-value = absorbance 250 nm/absorbance 260 nm of an acid extract of muscle tissue.

** Fragmentation index = 1000 x (residue wt./sample wt.).

*** Means within a column with different superscripts are significantly different (P<0.05).

Table 4-5. Percent water uptake, driploss, cookloss, and cooked meat moisture of hot-boned, chill-boned, and age-boned broiler breast meat obtained from carcasses stimulated with 240 volts for 0, 15, 30, or 45 seconds

Boning treatment	Stimulation duration (sec.)	%			
		Water uptake	Driploss	Cookloss	Cooked moisture
Hot-boned	0	9.83 ^{a*}	7.30 ^a	32.28 ^a	67.89 ^a
	15	9.93 ^a	6.39 ^a	30.87 ^a	68.46 ^a
	30	9.75 ^a	6.37 ^a	30.78 ^a	67.97 ^a
	45	8.84 ^a	5.98 ^a	31.77 ^a	67.64 ^a
Chill-boned	0	6.94 ^a	2.90 ^a	30.16 ^a	68.29 ^a
	15	5.60 ^a	1.08 ^a	27.36 ^a	68.54 ^a
	30	6.68 ^a	3.05 ^a	28.32 ^a	68.35 ^a
	45	5.50 ^a	0.94 ^a	28.92 ^a	68.62 ^a
Age-boned	0	5.33 ^a	1.36 ^a	26.39 ^a	68.88 ^a
	15	6.06 ^a	1.30 ^a	26.60 ^a	68.47 ^a
	30	4.65 ^a	1.01 ^a	26.63 ^a	68.35 ^a
	45	5.12 ^a	1.36 ^a	28.08 ^a	68.33 ^a

* Means within a column and a boning treatment with different superscripts are significantly different ($P < 0.05$).

driploss, and cookloss between hot-boned fillets and the other two boning treatments resulted because the hot-boned fillets were chilled as fillets without the skin, while the chill- and age-boned fillets were obtained from chilled carcasses. Hot-boned fillets had a greater surface area/unit weight in contact with the chilling medium thus increasing the amount of water uptake. Since there was a greater water uptake in the tissue there was a corresponding increase in driploss and cookloss. The carcasses from which chill-boned and age-boned fillets were obtained, whether stimulated or not, had water uptake well below the 8 or 12% limits imposed by the U.S.D.A. for ice-packed broilers (Brant et al., 1982). The hot-boned fillets, however, had water uptake close to the 12% limit for ice-packed fillets to be transported to and rehandled in distant markets, and exceeded the 8% water uptake limit for ice-packed poultry sent to nearby markets. Commercially, it may be necessary to reduce the time period allowed for chilling or reduce the amount of agitation during chilling to reduce percent water uptake in order to stay within U.S.D.A. limits if the product is ice-packed. If the processor wishes to chill-pack or freeze the fillets soon after processing, processors would be required to further limit water uptake in order to stay within U.S.D.A. regulations.

Conclusions

Postmortem electrical stimulation of broiler carcasses with 240 volts for as long as 45 seconds did not significantly improve the tenderness of hot-boned, chill-boned, or age-boned broiler breast

meat. Electrical stimulation increased the rate of rigor development as indicated by more rapid pH declines, and increased R-values. Electrical stimulation, however, did not alter the ultimate pH or R-values found in the age-boned fillets. Electrical stimulation did not significantly affect the sarcomere length or the fragmentation index of fillets obtained from any of the boning treatments.

Across the three boning treatments, sarcomere lengths, fragmentation index, pH, and R-values were significantly correlated to shear values. Within the three boning treatments, however, fragmentation index was the only variable significantly correlated with shear values within each of the boning treatments. Values for pH were correlated with shear values within the hot-boned treatments, sarcomere lengths with shear values within chill-boned fillets, and pH, R-values, sarcomere lengths, and fragmentation index were all correlated with shear values within the age-boned treatment. Within boning-simulation treatments very few significant correlations between shear values, and pH, R-value, sarcomere lengths, or fragmentation indexes existed. This indicates that pH, R-values (indicators of rigor development), or sarcomere lengths and meat tenderness were related to physiological changes that occur in muscle during rigor development, but did not necessarily have a cause and effect relationship. Stewart et al. (1985b) had similar findings for the relationship between tenderness and pH values.

CHAPTER V
EFFECTS OF ELECTRICAL STIMULATION AT VARIOUS VOLTAGES
ON THE TEXTURE OF BROILER BREAST MEAT

Introduction

Results from the third experiment demonstrated that electrical stimulation with 240 volts regardless of the stimulation duration did not induce tenderness in hot-boned, chill-boned, or age-boned broiler breast fillets. Maki and Froning (1984) reported that electrical stimulation of turkeys at 800 volts improved the tenderness of breast meat, but Dransfield et al. (1985) found that stimulation of turkeys with only 94 volts did not improve tenderness. Because of a lack of tenderness response in poultry using 45 and 240 volts, the effect of utilizing even higher stimulation voltages was examined in the second experiment. Because no tenderness response occurred using the longer stimulation durations for any of the boning treatments in the previous experiment (Chapter IV), the shortest duration of 15 seconds was selected for use in the third experiment.

The purpose of this study was to examine the effects of electrical stimulation at various voltages on the texture of hot-boned, chill-boned, and age-boned broiler breast meat and to determine an optimal stimulation voltage to induce a maximum tenderness response for a given stimulation duration for each boning treatment.

Materials and Methods

Basic Processing, Electrical Stimulation, and Boning

On two separate days (2 trials) 59 and 60 day-old male Cobb, feather-sexed broilers reared on a commercial type broiler diet were weighed to obtain a uniform weight range, fasted for 12 hours, and cooped 10/coop for a total of 120 birds (60/trial). Twelve birds per replication were processed, electrically stimulated, and boned as described in Chapter IV, except three carcasses were nonstimulated controls, while the remaining carcasses were subjected to stimulation for 15 seconds at 240, 530, or 820 volts. One carcass from each stimulation treatment was either hot-boned, chill-boned, or age-boned, for a total of 10 birds/treatment (boning time and voltage).

Analyses

Shear force, percent water uptake, driploss, cookloss, and cooked meat moisture, pH, sarcomere length, fragmentation index, and R-values were determined as outlined previously in Chapter IV.

Statistical Analysis

Data within each boning treatment were analyzed using analyses of variance, Duncan's Multiple Range Test (Steel and Torrie, 1960) and, where appropriate, orthogonal comparisons utilizing the General Linear Model system available in the Statistical Analysis Systems package (SAS, 1982). Shear force, pH, R-value, sarcomere length, and fragmentation index data were tested for correlations over the entire experiment, within boning treatments, and within boning-stimulation treatments using programs available in SAS, and standard error of the means were calculated for each boning-stimulation treatment (SAS,

1982). Data from both trials were combined since there were no significant trial x treatment interactions.

Results and Discussion

Shear values similar to those found in the previous experiment (Chapter IV) were obtained, with hot-boned and chill-boned broiler breast meat producing an unacceptably tough product compared to fillets that were age-boned (Table 5-1). As the time of boning increased, pH values decreased, and R-values and sarcomere lengths increased, and correlations of shear force and pH, R-values or sarcomere lengths were significant across the three boning treatments ($r=0.55$, -0.63 , and -0.58 , respectively; $P<0.01$) trends that were observed in the previous experiment. The differences in the pH and R-values between the two experiments for the hot-boned and chill-boned fillets could be related to differences in antemortem stress, and degree of starvation prior to slaughter. Shrimpton (1960) found that the degree of antemortem struggle affected the glycogen levels found in the muscle and subsequently affected the rate of postmortem glycolysis. Additionally, longer feed withdrawal periods had a tendency to decrease the rate of pH decline and caused considerable variation in the rate of pH decline compared to birds fed prior to slaughter.

The fragmentation index data (Table 5-1) did not follow the same trends that were evident in the previous experiment (Chapter IV) although shear values and fragmentation indexes were positively and significantly correlated over the entire experiment, as in Chapter IV

Table 5-1. Shear values, pH, R-values, sarcomere lengths, and fragmentation indexes of hot-boned, chill-boned, and age-boned broiler breast meat obtained from nonstimulated (control) carcasses

Boning treatment	Shear value (kg force/g sample)	pH	R-value*	Sarcomere length (μm)	Fragmentation** index
Hot-boned	13.6 \pm 0.94***	6.28 \pm 0.04	0.93 \pm 0.04	1.46 \pm 0.06	264 \pm 39
Chill-boned	9.4 \pm 1.17	6.12 \pm 0.04	0.90 \pm 0.04	1.50 \pm 0.05	354 \pm 47
Age-boned	3.7 \pm 0.22	5.69 \pm 0.04	1.33 \pm 0.07	1.80 \pm 0.04	204 \pm 32

* R-value = absorbance 250 nm/absorbance 260 nm of an acid extract of muscle tissue.

** Fragmentation index = 1000 x (residue wt./sample wt.).

*** Means \pm standard error of the mean.

($r=0.41$, $P<0.01$). This difference was probably due to the large variation in the data, which arose from difficulties in controlling the degree of thaw in the samples prior to homogenization. Samples that remained frozen prior to homogenization produced higher fragmentation indexes than samples that were thawed. In the previous experiment, the samples were held in the freezer until homogenization while the samples in this experiment were allowed to thaw for approximately 15 minutes prior to homogenization.

Electrical stimulation for 15 seconds regardless of the voltage utilized did not significantly improve the tenderness of hot-boned broiler breast meat ($P<0.05$) (Table 5-2). However, orthogonal comparison of fillets from nonstimulated vs. stimulated carcasses revealed a trend for stimulation to increase the shear values of hot-boned broiler breast meat ($P < 0.12$). Utilization of high voltages (530 and 820V) significantly increased the rate of postmortem rigor development as indicated by significantly lower pH values and significantly higher R-values compared to fillets from nonstimulated and low voltage stimulated (240V) carcasses (Table 5-2).

Electrical stimulation of beef has been utilized to improve tenderness by hastening the onset of rigor so that cold shortening could be avoided and hot-boning utilized (Carse, 1973; Cross and Tennent, 1980). Savell et al. (1978b) demonstrated that electrical stimulation could be used to avoid toughness problems caused by rapid processing, but that electrical stimulation also improved the tenderness of conventionally processed beef. Much work has been published examining the effects of various voltages ranging from

Table 5-2. Mean shear values, pH, R-values, sarcomere lengths, and fragmentation indexes \pm standard error of the mean of hot-boned broiler breast meat obtained from carcasses stimulated for 15 seconds with 0, 240, 530, or 820 volts

Stimulation voltage (v)	Shear value (kg force/g sample)	pH	R-value*	Sarcomere length (μ m)	Fragmentation** Index
0	13.6 ^a \pm 0.94***	6.28 ^a \pm 0.04	0.93 ^a \pm 0.04	1.46 ^a \pm 0.06	264 ^d \pm 39
240	16.3 ^a \pm 1.59	6.15 ^{ab} \pm 0.05	0.92 ^a \pm 0.02	1.60 ^b \pm 0.02	363 ^{ab} \pm 49
530	16.2 ^a \pm 1.38	6.05 ^b \pm 0.05	1.00 ^{ab} \pm 0.04	1.55 ^b \pm 0.03	409 ^b \pm 57
820	16.2 ^a \pm 1.64	6.06 ^b \pm 0.03	1.04 ^b \pm 0.03	1.62 ^b \pm 0.02	413 ^b \pm 70

* R-value = absorbance 250 nm/absorbance 260 nm of an acid extract of muscle tissue.

** Fragmentation index = 1000 x (residue wt./sample wt.).

*** Means within a column with different superscripts are significantly different (P<0.05).

20 to 3,600V, and even very low voltages were effective in inducing tenderness in beef (Taylor and Marshall, 1980). High voltage systems, however, were recommended for use in conjunction with hot-boning or rapid chilling because as the voltage increases there is a corresponding increase in the rate of rigor onset (Carse, 1973; Bouton et al., 1980) which decreases the length of the holding time required prior to rapid chilling or boning. Even though voltages as high as 820 volts were utilized in this study, the tenderness of the hot-boned meat was not improved, in spite of a significant increase in the rate of rigor development.

In this experiment, hot-boned fillets from stimulated and nonstimulated carcasses, were removed from the carcasses prior to full rigor development, as evidenced by relatively high pH values, low R-values, and a lack of muscle stiffness. Removing the prerigor meat from the bone releases physical anatomical restraints allowing for unimpeded muscle contraction while the muscle is progressing into rigor. The act of hot-boning also provides the meat with a stimulus, inducing contraction to occur. The low sarcomere length values reflect this increase in the degree of contraction (Table 5-2), which has been related to increased toughness (Herring et al., 1967).

Cold shortening also may have contributed to toughening associated with hot-boning and the smaller shear values associated with the fillets obtained from nonstimulated carcasses. The hot-boned fillets were subjected to low temperatures (1°C) within 20 minutes of boning and it is likely that the fillets were progressing into rigor at this time causing the cold shortening. Locker and Hagyard (1963)

found that subjecting isolated prerigor beef to temperatures between 0 and 2°C caused rapid and extreme shortening compared to muscle held at higher temperatures. Marsh and Leet (1966) demonstrated that this shortening caused an increase in the toughness of the meat. Since the nonstimulated carcasses had a slower rate of rigor development (Table 5-2), ATP was available for muscle contraction possibly causing a more severe form of cold shortening than that observed in the fillets from stimulated carcasses as evidenced by the significantly shorter sarcomere lengths (Table 5-2) for the nonstimulated compared to the stimulated carcasses. This extreme shortening found in the nonstimulated fillets caused a slight improvement in tenderness. Marsh et al. (1974) found that micrographs of severely contracted muscle were not uniform, with zones of severely shortened sarcomeres and, in contrast, regions which were physically disrupted or stretched. They concluded that severe shortening actually caused tenderization as a result of physical disruption of the fibers. Marsh and Leet (1966) documented the tenderizing effect, finding that up to 40% shortening increased the toughness in beef, but shortening to a greater extent caused a linear decrease in shear values.

The hypothesis of severe shortening inducing tenderization in the nonstimulated fillets was substantiated by the fragmentation index data (Table 5-2). As earlier stated, the severe shortening found in the nonstimulated fillets could have caused physical fibril disruption which would decrease the fragmentation index of the myofibrils since fragmentation index is an indicator of structural weakening of the myofibrils. Boning the nonstimulated fillets at high pH's (>6.15)

resulted in extremely shortened sarcomeres producing slight tenderization caused by fibril disruption, as evidenced by low fragmentation indexes. Electrical stimulation prevented the extreme shortening, reducing any minor tenderization caused by extreme shortening.

An additional reason for the lack of a tenderness response in fillets from electrically stimulated carcasses may be related to a lack of an enzymatic response. Dutson et al. (1980) suggested autolytic proteolysis, caused by the lysosomal enzymes, β -glucuronidase and cathepsin-C, as one mechanism for the tenderization response caused by electrical stimulation. In beef, electrical stimulation produces a condition of low pH while the temperature of the muscle is still relatively high. Under these conditions, lysosomal enzymes degraded myofibrillar proteins (Schwartz and Bird, 1977). In this experiment the fillets were deboned while the pH was still relatively high, and within 10-15 minutes the fillets were chilled, preventing the development of optimal conditions needed for the action of the lysosomal enzymes.

Calcium-activated factor (CAF) is another enzyme that has been associated with meat tenderization. Marsh et al. (1981) found that holding beef at relatively high temperatures at a neutral pH promoted the development of tenderness, suggesting that an enzyme or enzyme system active at neutral pH and high temperatures could have been responsible for some tenderness development during rigor. Purified preparations of CAF degraded the myofibrillar proteins, tropomyosin, troponin-I, troponin-T, the Z-line, and the gap filaments (Locker

et al., 1977). It would seem unlikely, however, that CAF had an active role in tenderization in this experiment since CAF is not active below pH 6.5 (Dayton et al., 1975). Rapid pH declines in hot-boned meat, whether stimulated or not, produced conditions unconvincing to CAF activity.

Within the hot-boned treatment, sarcomere length was the only variable significantly correlated with shear values ($r=-.33$, $P<0.01$), indicating that pH, R-values, and fragmentation indexes did not have a direct cause and effect relationship with shear values, but that differences in tenderness were more closely associated with sarcomere lengths than the other variables. Changes occurring in sarcomere length and fragmentation index, however, were significantly correlated with pH, indicating that the degree of contraction and myofibril fragmentability in prerigor meat is related to the development of rigor mortis, and that tenderness in hot-boned meat was indirectly related point during rigor development at which the fillets were boned, and the myofibril fragmentation did have some role in tenderness but large variation in the data obscured any significant differences in fragmentation indexes between treatments.

In chill-boned broiler breast meat, no significant improvement in tenderness was observed when carcasses were stimulated at 240, or 530 volts, but a significant tenderness improvement occurred when carcasses were stimulated at 820 volts (Table 5-3). Stimulation with 820 volts reduced the average shear value of chill-boned meat to a level below the value of 8 kg/g suggested by Simpson and Goodwin as a threshold for unacceptability in tenderness. Many processors have

Table 5-3. Mean shear values, pH, R-values, sarcomere lengths, and fragmentation indexes \pm standard error of the mean of chill-boned broiler breast meat obtained from carcasses stimulated for 15 seconds with 0, 240, 530, or 820 volts

Stimulation voltage (v)	Shear value (kg force/g sample)	pH	R-value*	Sarcomere length (μ m)	Fragmentation** index
0	9.4 ^a \pm 1.17***	6.12 ^a \pm 0.04	0.90 ^a \pm 0.04	1.50 ^a \pm 0.05	354 ^a \pm 47
240	9.2 ^a \pm 0.97	5.91 ^b \pm 0.06	1.07 ^{ab} \pm 0.07	1.60 ^{ab} \pm 0.03	304 ^a \pm 58
530	8.2 ^a \pm 0.94	5.96 ^b \pm 0.06	1.17 ^b \pm 0.06	1.64 ^b \pm 0.05	206 ^a \pm 41
820	6.5 ^b \pm 0.84	5.83 ^b \pm 0.06	1.12 ^b \pm 0.06	1.68 ^b \pm 0.03	301 ^a \pm 44

* R-value = absorbance 250 nm/absorbance 260 nm of an acid extract of muscle tissue.

** Fragmentation index = 1000 x (residue wt./sample wt.).

*** Means within a column with different superscripts are significantly different (P<0.05).

been chill-boning meat in spite of the tenderness problems encountered. Results from this study indicated that postmortem electrical stimulation could be used to solve the tenderness problem. Electrical stimulation systems should be fairly easy to implement in current processing schemes, particularly with a stimulation duration as short as 15 seconds. Some processors are currently poststunning carcasses after bleeding to reduce variation in tenderness due to struggling of misstunned birds. Postslaughter stunning devices utilized equipment similar to preslaughter stunning devices which operate at 800 volts. Processors would need to make modifications increasing the length of the poststun period from 1 or 2 seconds to 15 seconds in order to achieve the desired response.

Electrical stimulation significantly reduced the pH at the time of chill-boning, and there was a trend toward lower pH values as the stimulation voltage increased (Table 5-3). The increase in the rate of the rigor development was also evident in the increase in R-values as stimulation voltage increased. As the stimulation voltage increased, there was a corresponding significant increase in sarcomere lengths. As earlier discussed, longer sarcomere lengths have been found to correlate to lower shear values (Herring et al., 1967), a trend evident in chill-boned fillets, with shear values significantly and negatively correlating to sarcomere lengths ($r=-0.32$, $P<0.05$). Results from this study (Table 5-3) were consistent with findings of Maki and Froning (1984) who found that electrical stimulation with 800 volts improved the tenderness of turkey breast meat and caused an increase in sarcomere lengths over nonstimulated carcasses.

Although fragmentation indexes were not significantly different between the treatments ($P < 0.05$), correlations between shear values and fragmentation indexes were significantly correlated ($r = 0.42$, $P < 0.01$) indicating that improvements in tenderness in the fillets stimulated at 820V were related to increased fragmentability. Sayre (1970) and Culler et al. (1978) demonstrated that the fragmentability of myofibrils was related to the tenderness of poultry and beef, respectively, with tougher meat having a greater resistance to fragmentation.

Sonaiya et al. (1982) observed that the improvement in tenderness of electrically stimulated beef carcasses over nonstimulated carcasses appeared to be related to myofibril disruption as indicated by increases in the fragmentability of the myofibrils. Savell et al. (1978a) and Sorinmade et al. (1982) found ill-defined I-bands, Z-lines, contracture bands, and stretch sarcomeres in electrically stimulated meat, that was not evident in nonstimulated control muscles. Savell et al. (1978a) suggested this led to a loss of structural integrity and increased tenderness. The lack of a significant myofibril fragmentability response with electrical stimulation at the $\alpha = 0.05$ level was related to the large amount of variation in the data caused by problems associated with controlling the degree of thaw in samples prior to homogenization.

As with hot-boned meat, pH and R-values were not significantly correlated with shear values but sarcomere lengths were significantly correlated to pH, R-values, and shear force values ($r = -0.38$, $P < 0.02$; $r = 0.39$, $P < 0.02$; $r = -0.32$, $P < 0.05$, respectively). Fragmentation index

was also significantly and negatively correlated with shear values. Results indicated that tenderness improvements in chill-boned fillets with electrical stimulation at 820 volts were related to increased sarcomere lengths and decreased fragmentation indexes. Increasing sarcomere lengths appeared to be related to increases in the rate of rigor development caused by high voltage stimulation (820V). Decreases in shear values related to decreases in fragmentation indexes, however, did not appear to be directly caused by changes in pH or R-value but instead could have been a direct result of physical fiber disruption caused by more severe muscle contractions at higher voltages since pH and R-values were not correlated to fragmentation indexes. Additional evidence for this hypothesis is found in correlations between shear values and fragmentation indexes within boning-stimulation treatments. Shear values from nonstimulated chill-boned fillets were not significantly correlated with fragmentation indexes ($r=0.09$, $P<0.80$). Shear values and fragmentation indexes, however, were significantly correlated within each of the stimulated, chill-boned treatments (240V: $r=0.64$, $P<0.05$; 530V: $r=0.58$, $P<0.01$; 530V: $r=0.45$, $P<0.10$).

Unlike the results obtained for the chill-boned meat, there was no significant improvement in the tenderness of the age-boned fillets even with the use of high voltage stimulation (820V) (Table 5-4). It is possible that stimulation increased the tenderness of age-boned poultry meat, as found in red meats, but such low shear values approached the lower limit of detectability for the shear method used in this experiment, which has been reported to be 2 to 3 kg force/g

Table 5-4. Mean shear values, pH, R-values, sarcomere lengths, and fragmentation indexes \pm standard error of the mean of age-boned broiler breast meat obtained from carcasses stimulated for 15 seconds with 0, 240, 530, or 820 volts

Stimulation voltage (v)	Shear value (kg force/g sample)	pH	R-value*	Sarcomere length (μ m)	Fragmentation** index
0	3.7 ^a \pm 0.22***	5.69 ^a \pm 0.04	1.33 ^a \pm 0.07	1.80 ^a \pm 0.04	204 ^a \pm 32
240	3.9 ^a \pm 0.31	5.67 ^a \pm 0.06	1.44 ^a \pm 0.01	1.76 ^a \pm 0.03	186 ^a \pm 38
530	4.0 ^a \pm 0.36	5.70 ^a \pm 0.05	1.42 ^a \pm 0.01	1.75 ^a \pm 0.02	215 ^a \pm 59
820	3.6 ^a \pm 0.22	5.80 ^a \pm 0.08	1.41 ^b \pm 0.01	1.82 ^a \pm 0.03	168 ^a \pm 45

* R-Value = absorbance 250 nm/absorbance 260 nm of an acid extract of muscle tissue.

** Fragmentation index = 1000 x (residue wt./sample wt.).

*** Means within a column with different superscripts are significantly different (P<0.05).

sample (Janky et al., 1982). As the lower limit of shear force was approached, the reduction in toughness became insignificant because the variation between samples within a stimulation treatment remained constant but the difference between treatment means was reduced.

Electrical stimulation did not produce any significant differences in the pH or R-values of age-boned meat regardless of the stimulation voltage (Table 5-4). Khan and Frey (1971) reported that pH and R-values reached their ultimate levels within 24 and 48 hours postmortem, respectively. Since the age-boned fillets were aged 48 hours prior to boning, no differences in the pH or R-values would be expected because the pH and ATP levels would have already been achieved. Electrical stimulation increased the rate of rigor development, as evidenced by lower pH and higher R-values in stimulated hot-boned and chill-boned fillets, but electrical stimulation did not alter the ultimate pH (Pearson and Dutson, 1985), or the ultimate concentration of ATP, ADP, AMP, CP, IMP, or inosine (Calkins et al., 1982) of meat.

Electrical stimulation had no significant effect on the sarcomere lengths or fragmentation indexes of age-boned breast fillets, which corresponds to the shear value data (Table 5-4). As previously discussed, longer sarcomere lengths (Herring et al., 1967) and lower fragmentation indexes (Culler et al., 1978) have been associated with improved meat tenderness.

Values of pH were significantly correlated to shear values ($r=-0.37$, $P<0.02$) and sarcomere lengths within the chill-boned treatment. This indicates that ultimate pH levels are related to the

tenderness of age-boned meat as demonstrated by shear values and sarcomere lengths, but the differences in the tenderness of age-boned meat, regardless of stimulation voltage are so small they are insignificant.

Electrical stimulation, regardless of the voltage, had no significant effect on the WHC of hot-boned broiler breast meat as reflected in the nonsignificant differences in percent water uptake, driploss, cookloss, or cooked meat moisture (Table 5-5). The same was true for the chill-boned and age-boned fillets with two exceptions (Table 5-5). Chill-boned fillets from carcasses stimulated at 820 volts had significantly higher driploss than nonstimulated controls. There was a numeric, but nonsignificant, trend in this study for the carcasses that were stimulated with 820 volts to have a slightly increased water uptake compared to carcasses from the other treatments. It would then follow that the 820 volt carcasses would have an increased driploss. It was unlikely that this was truly a significant effect related to the stimulation treatment, because there was a large amount of variation between individual carcasses within the same treatment. The same was true for the significant increase in driploss for age-boned carcasses stimulated with 530 volts. These carcasses had an increased but nonsignificant water uptake, so it would follow that there would be proportionately higher driploss, since the amount of driploss was proportional to the amount of water picked up during chilling (Kiker and Farr, 1975).

Table 5-5. Percent water uptake, driploss, cookloss, and cooked meat moisture of hot-boned, chill-boned, and age-boned broiler breast meat obtained from carcasses stimulated for 15 seconds with 0, 240, 530, and 820 volts

Boning treatment	Stimulation voltage (V)	%			
		Water uptake	Driploss	Cookloss	Cooked moisture
Hot-boned	0	11.56 ^{a*}	8.34 ^a	27.19 ^a	69.64 ^a
	240	11.30 ^a	7.65 ^a	27.22 ^a	69.02 ^a
	530	10.51 ^a	7.36 ^a	24.97 ^a	70.42 ^a
	820	11.12 ^a	6.74 ^a	27.28 ^a	68.80 ^a
Chill-boned	0	5.10 ^a	0.74 ^a	20.98 ^a	70.21 ^a
	240	5.40 ^a	1.79 ^{ab}	25.05 ^a	69.53 ^a
	530	5.42 ^a	1.24 ^{ab}	25.66 ^a	69.56 ^a
	820	6.36 ^a	2.22 ^b	23.97 ^a	69.76 ^a
Age-boned	0	5.68 ^a	2.10 ^a	23.80 ^a	70.39 ^a
	240	5.48 ^a	2.05 ^a	25.80 ^a	70.00 ^a
	530	7.41 ^a	3.42 ^b	25.00 ^a	70.27 ^a
	820	5.63 ^a	1.97 ^a	23.38 ^a	70.17 ^a

* Means within a column and a boning treatment with different superscripts are significantly different ($P < 0.05$).

Conclusions

In summary, postmortem electrical stimulation of broiler carcasses with 820 volts improved the tenderness of fillets boned immediately after chilling, and it appeared that tenderization was related to increased sarcomere lengths and myofibril fragmentability.

An improvement in texture was not noted in hot-boned or age-boned fillets. There was a significant increase in sarcomere lengths of hot-boned fillets from stimulated carcasses, but this increase did not lead to the improvement in texture as expected. The increase in sarcomere lengths appeared to be offset by a substantial decrease in the fragmentability of stimulated meat. Postmortem electrical stimulation increased the rate rigor development and there was a trend for higher voltages to have an even greater effect on this rate increase. Correlations between shear values and pH or R-values, as discussed earlier, tended to indicate that there was not a direct relationship between pH and shear values upon examining the data from the three different boning treatments and within boning-stimulation treatments. Stewart et al. (1984a) suggested that the development of tenderness and pH in poultry meat were related to similar biochemical processes but their relationship was not of a direct cause and effect nature. The same appeared to be true for the R-value.

SUMMARY AND CONCLUSIONS

Electrical stimulation, regardless of the stimulation duration or voltage, had no significant effect on the tenderness of hot-boned or age-boned broiler breast meat. However, high voltage (820V) postmortem electrical stimulation of broiler carcasses significantly improved the tenderness of broiler breast meat that had been harvested immediately after chilling, producing an acceptably tender product. Processors have been utilizing chill-boning in order to efficiently meet the increased demand for boned meat, in spite of the toughness problems encountered with the technique. Boned meat and cut-up parts are high value marketable products compared to whole ready-to-cook carcasses. Shelton (1985) estimated that, by the year 2000, nearly 90% of poultry meat will be marketed as cut-up or boned product, but that the tenderness problems associated with chill-boning will force processors to adopt a minimum 4 hour aging period prior to boning. This aging requirement has resulted in and will result in increased production costs due to increased labor, handling, and storage requirements.

The use of high voltage postmortem electrical stimulation could be applied to reduce the toughness problems associated with chill-boning and could save processors from instituting or continuing to use a minimum 4 hour aging period prior to boning. Electrical stimulation systems would be fairly easy to implement in current processing

schemes, particularly with stimulation durations as short as 15 seconds. Some processors have been utilizing a type of electrical stimulation, applied to the carcass after bleeding, referred to as poststunning. Poststunning has been used to reduce variation in tenderness that is caused by struggling of misstunned birds and has been accomplished using 800 volts, the same voltage used for electrical stunning. Processors only may need to make modifications increasing the length of the poststun period from 1 or 2 seconds to 15 seconds to achieve the desired tenderness response.

Postmortem electrical stimulation increased the rate of rigor development as demonstrated by higher R-values and lower pH values in hot-boned and chill-boned fillets from stimulated carcasses compared to fillets from nonstimulated carcasses. Increasing stimulation voltage and duration caused an increase in the rate of rigor development. Electrical stimulation, however, did not affect the ultimate pH or R-value of the breast meat as demonstrated by a lack of significant difference in R-values or pH values between stimulated and nonstimulated age-boned meat. Results tended to indicate that there was not a direct relationship between pH and shear values upon examining the data from the three boning treatments. As Stewart et al. (1984a) suggested, the development of tenderness in poultry meat was related to similar processes but their relationship was not of a direct cause and effect nature. The same appeared to be true for the R-values.

High voltage electrical stimulation (530 and 820) of carcasses caused an increase in the sarcomere lengths of hot-boned and

chill-boned breast fillets. Improvements in tenderness associated with longer sarcomeres were observed in chill-boned fillets, but not in hot-boned fillets where increased sarcomere lengths appeared to be offset by significant decreases in the fragmentability of the myofibrils. The fragmentability of chill-boned fillets was not significantly effected by high voltage stimulation ($P < 0.05$), but was correlated to tenderness indicating the increased fragmentability did play a role in tenderization.

Low voltage stimulation (240V) did not affect the fragmentation index of hot- or chill-boned fillets or the sarcomere lengths of hot-boned fillets, regardless of stimulation duration. Low voltage stimulation had an inconsistent effect on the sarcomere lengths of chill-boned fillets with increases observed in one experiment but not the other.

Regardless of the stimulation voltage or duration, electrical stimulation did not significantly effect the sarcomere lengths or fragmentation indexes of age-boned meat.

Electrical stimulation had no significant effect on the water holding capacity of poultry meat as demonstrated by a lack of significant differences in percent water uptake during chilling of carcasses or hot-boned fillets, the driploss of hot-boned and chill-boned fillets or whole carcasses, or the percent cookloss and cooked moisture of the hot-, chill-, or age-boned fillets regardless of the stimulation duration or voltage.

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BIOGRAPHICAL SKETCH

The author, Leslie Thompson, was born April 9, 1959, in Pasadena, Texas. During her youth, the author traveled and lived throughout the U.S. and the Phillipines with her parents, Major and Mrs. V. B. Thompson, eventually attending Newberry Park High School in Thousand Oaks, California. In 1977, she graduated from Crestview Senior High School in Crestview, Florida. She attended the University of Florida receiving a Bachelor of Science in Agriculture degree in August of 1980, and a Master of Science degree with specialization in poultry products technology in August of 1983. Currently, the author is a doctoral candidate pursuing a Ph.D. in food science and human nutrition at the University of Florida.

During her college career she was a member of the Poultry Science Club, serving as Treasurer and Vice President; Alpha Zeta; Gamma Sigma Delta; and the University of Florida Horse Teaching Unit. As an undergraduate and master's candidate she was employed part-time at the University of Florida Poultry Research Unit, and during her Ph.D. program the author received a teaching/research assistantship from the Poultry Science Department.

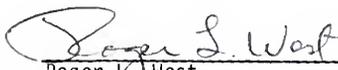
The author was the recipient of the Wallace-Hi-Line Hatcheries Scholarship, Ohio State Scholarship, Beta Club Scholarship, and the Julian S. Moore Memorial Merit Award for Outstanding Undergraduate. Professional memberships include the Institute of Food Technologists and Poultry Science Association.

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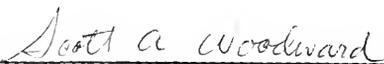
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