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Electrical Stimulation in Meat Processing

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17.1 Introduction

During postmortem storage, the muscle undergoes a series of biochemical, histological, and physical events, all together called rigor mortis. If one or several of these events are modified, product acceptability may be altered (Stiffler and others 1982). Tenderness, in addition to color and flavor, is considered the most important characteristic of meat (Savell and others 1977; McKeith and others 1979; Elgasim and others 1981; Soria and Corva 2004; Castañeda and others 2005). Looking for an efficient postmortem tenderizing method is a result of consumers’ demand for good tasting and uniform quality meat (Stiffler and others 1982). Several researchers developed methods to improve meat tenderness; muscle contractile proteins, connective tissue, or both are usually affected by these processes.

The factors determining the quality of raw meat, as well as meat subjected to refrigeration, freezing, or any other treatment involve its nutritive value, sanitation, sensory characteristics, and its possible use as raw material for further processing. These factors can be grouped under those originated before birth or genetic; occurring during the animal’s growth or environmental; and those resulting from meat handling and processing, including meat ripening, storage, and specific operations for meat transformation into fabricated products. All of these factors determine meat preservation and quality (Stiffler and others 1982).

Electric stimulation (ES) is one step in meat transformation; it enhances sensory characteristics (color, odor and flavor, and tenderness). Early studies in ES were carried out during the 1940s in the United States, although without considerable success. Sams (1999) pointed out that ES meat was industrially produced in the 1950s, aimed for meat processing. During the 1970s, this method was used to avoid cold shortening in lamb carcasses. In 1975, some prototype stimulators were incorporated in American abattoirs; these prototypes were considerably improved during the following decades and at present some ES equipments handle up to 300 animals per hour (Guerrero and others 2004).

ES involves the application of an electric current to the carcass of recently slaughtered and eviscerated animals. By supplying an electric current, the muscle fibers extensively contract and suddenly undergo extension preventing further contraction or rigor mortis and, as a consequence, further muscle shortening. This effect is also known as physical disruption of the myofibrillar matrix or proteolysis acceleration; it increases the glycolysis rate and causes an immediate pH drop (Elgasim and others 1981; Byrne and others 2000; Hwang and others 2003).
The effect of ES on meat quality is discussed in this chapter, reported results are discussed, and biochemical and sensory characteristics of stimulated and nonstimulated carcass meat are compared.

17.2 Effect of ES on Meat Sensory Characteristics

Sensory characteristics are possibly the main factor determining meat quality. Failure in fulfilling characteristics expected by the consumer will result in economic losses for the producer; they depend on numerous factors including handling before and after slaughtering. Therefore, ES application also results in improving the sensory characteristics.

Radish and others (1983) reported that in a conventional slaughtering process, considerable time is consumed between slaughtering and getting the right carcass quality to be ready for marketing as meat. However, the time elapsed can be sensibly reduced by applying ES. On the other hand, Channon and others (2003a) comment that ES benefits largely depend on the stunning method as well as the voltage applied when electric stunning is used; time elapsed after killing also influences the optimal conditions for ES.

Studies reported by Elgasim and others (1981) on 459–510 kg American beef stimulated at 600 V, 7 A, 7 Hz for 1 min showed that muscle pH and temperature after rigor mortis affects meat tenderness as well as other sensory properties. Tenderness was analyzed using a Warner–Bratzler shearing device and by sensory evaluation methods. The panelists detected significant differences in the odor, flavor, appearance, and juiciness of the stimulated meat (Pospiech and others 2003).

Similar results were obtained in studies carried out by Savell and others (1978) on five conventionally slaughtered steer carcasses. After 1 h postmortem carcass, right halves were stimulated at 50 pulses for 0.5–1.0 s, 100 V, 5 A, 50–60 cycles/s; the left sides were taken as control. Both sides were then refrigerated, Longissimus muscle samples 20–24 h postmortem from both sides were analyzed for sensory characteristics and sarcomere length. The results indicated that samples taken from the stimulated half were less juicy, more tender, and with better flavor, having less detectable connective tissue; hardness and cooking loss were also reduced.

Davel and others (2003) studied sensory characteristics of meat obtained from stimulated carcasses of 22 castrated Dorper sheep (40–50 kg). Stimulation was at 20 V, 45 Hz for 45 s, the carcasses were then refrigerated, Longissimus muscle samples 20–24 h postmortem from both sides were analyzed for sensory characteristics and sarcomere length. The right Longissimus lumborum was grilled at 160°C, 73°C internal temperature. Results showed higher acceptability of stimulated as compared to nonstimulated samples. ES did not affect cooking losses, associated with weight at sacrifice and carcass fat.

Studies carried out with 12 female alpacas, applying various stimulation voltages (500 and 600 V for 30 and 60 s) after 1–24 h postmortem, reported a significant effect on Longissimus dorsi pH between treated and nontreated meat. The difference was mainly due to time and applied voltage (500 V/30 s) causing a rapid decrease in pH24 (5.27), as compared to the control group (pH24 6.31). In general stimulated meat has pH < 6.0 for the first 24 h poststimulation; conversely, nonstimulated meat has pH = 6.0. This phenomenon, according to the authors, could be due to the fact that ES increases the rate in muscle contraction cycles, accelerating exhaustion of glucose reserves and increasing lactic acid production (Guerrero and others 2004).

Similar results were obtained by Byrne and others (2000) in carcasses obtained from 47 calves; pH decreased during postmortem storage as a result of lactic acid accumulation due to glycolysis, that is, pH 6.56 after 2 h and pH 5.48 after 24 h postmortem. No DFD carcass meat was observed.

Young and others (1999) studied color changes in 96 chicken carcasses; half of the animals were electrically stimulated during stunning. The authors concluded that ES produced significantly brighter meat but less intense redness in the Pectoralis major muscle. pH in ES meat rapidly decreased, whereas pH decreased in control samples (non-ES) to the same levels in amount in 2 h. The bright color of the stimulated carcasses was probably due to rapid muscle acidification caused by protein denaturation which, in turn, caused higher light reflectance on the meat surface (Warriss 2000).

Voltage intensity and duration also affect the meat color. One hundred ES bovine carcasses were studied by Roeber and others (2000); the positive electrode was placed in the Latissimus dorsi muscle.
and the negative in the Biceps femoris muscle. Average 100 V voltage was compared against high (300 V) voltage and 11 cps and 16 cps duration at 60 Hz. Color of stimulated Longissimus muscles was brighter, redder, and less blue as compared to nonstimulated muscles. Conversely, no differences were found with respect to water loss during cooking; the authors explained this observation to the fact that the total storage time in this study was 3 days, considerably less than in other studies that report an increase in water loss after 7 days total storage time. The authors also concluded that ES promotes a reduction in carcass-ripening time, in turn producing leaner and more desirable colored meat.

Studies carried out by Channon and others (2003b) concluded that with the application of 50–200 mA for 30 s constant current to previously bled swine carcasses, the time to reach final pH values was 40 min, as compared to 8 h in non-ES carcasses. However, the authors also reported that ES increased exudation.

It has been demonstrated that ES increases beef palatability (Stiffler and others 1982), improves color, and reduces ripening time; it also reduces the presence of dark-cutting beef (McKeith and others 1981). Warriss (2000) reports that ES affects meat acceptability due to flavor changes. Nonetheless, studies carried out by Guerrero and others (2004), showed flavor improvement in 600 V/30 s stimulated carcasses. Possibly, at this voltage stimulation free amino acids react with other chemicals, producing flavor-related compounds, such as those resulting from Maillard reactions (Gianelli and others 2003).

The effect of ES and evisceration on flavor was studied in 390 bovines (young bullocks and calves) by McKeith and others (1981). The carcasses were eviscerated and stimulated 5 min after bleeding, and 20 and 30 min after evisceration, and compared to a control (nonstimulated carcasses). ES was applied at 150 V or 550 V for 1 min (16 pulses) or 2 min (32 pulses); the impulses were for 1.8 s with 1.8 s intervals between them. The authors found that there was no flavor improvement when ES for 1 or 2 min was applied; however, when the carcasses were stimulated with 550 V, leaner, redder, and more tender with better flavor meat was obtained, as compared to meat from carcasses stimulated with 150 V. It was concluded that short time (1 min) and high voltage (550 V) ES can be applied during different dressing in order to increase meat palatability.

ES also affects meat odor. Data obtained by Guerrero and others (2004) indicated that on applying 500 V/60 s, the meat odor is significantly reduced. Conversely, studies by Owens and Sams (1997) in 36 electrically stimulated female turkeys (average weight 7 kg, 10 pulses in the neck region at 570 V, 45 mA, 2 s and 1 s) showed that muscular metabolism is accelerated after 2 h postmortem, decreasing pH and preventing excessive sarcomere shortening. However, ES had no effect on the cutting, water loss during cooking, fragmentation index, or color values, suggesting that postmortem ES provides benefits that justify applying this method in turkey processing.

Hertog-Meischke and others (1997) studied ES to 60 bull carcasses (2 years old, 368–410 kg carcass weight); eight carcasses were electrically stimulated (85 V, 14 Hz, 15 s immediately after bleeding). The results showed that ES caused high drip loss, possibly as a result of myosin denaturation caused by pH and temperature postmortem reduction.

Therefore, as shown by the results obtained from various authors, several sensory characteristics such as odor, color and flavor, juiciness and, mainly, tenderness are improved by the application of ES. However, other factors must be considered in these results such as animal species, genetics, handling, and animal age and breed.

17.3 Physiology and Biochemistry of ES Meat

ES accelerates two of the leading postmortem processes: pH decrease to values lower than 6.4 and rigor mortis onset by accelerating the glycolysis rate. During ES application, the rate of both processes is considerably increased but decreases when electricity application ceases.

ES also prevents thaw rigor in hot carcass, when meat is frozen before rigor mortis resolution. In some cases, ES is applied to excised muscles, although it should be carried out within 30 min after sacrifice, when muscles are still attached to the skeleton (Prändl and others 1994).

ES allows carcass or primal cuts to be refrigerated or frozen just at the end of the slaughter line, without previously allowing onset and resolution of rigor mortis. In this way, the advantage of using ES is mainly in avoiding carcass shorting during postmortem refrigerated shortening due to rapid temperature decrease.
From the physiological point of view, the mechanism responsible for ES meat tenderization is by Ca\(^{2+}\) ion-release from the sarcoplasmatic reticulum; myosin-ATPase is then activated promoting muscle contraction. Calcium liberated during muscular contraction stimulates calpains, specific sarcoplasmic proteases disrupting the Z-line. When this event occurs, muscle temperature is still high (around 30°C) and pH is above 6.5, and calpains are highly active. Lysosomes are also probably disrupted releasing cathepsins, other endogenous proteases, which also promote muscle proteolysis (Warriss 2000).

Conversely, during cold shortening, when hot carcasses are refrigerated (at approximately 10–15°C) in prerigor conditions, before dissipation of body heat, calcium ions are massively liberated from the sarcoplasm by disruption of the calcium pump, while myosin-ATPase is still active; at the same time, muscle ATP concentration is still high providing enough energy for contraction. As a result, the muscle severely contracts producing very tough meat, which is even more evident when cooked.

Toughening is even more marked when thaw rigor takes place. This occurs when the prerigor meat is frozen (at less than –10°C) (Lawrie 1991). In this situation, ATP has not depleted yet; calcium remains in the sarcoplasmic reticulum, even though the calcium pump is disrupted due to freezing. When thawed, massive calcium release occurs, while ATP is still at high concentrations, and the result is an extremely severe shortening, even more than in cold shortening. It has been reported that an excised muscle undergoing thaw rigor shortens up to 30% of its original length (Lawrie 1991). However, muscle length in thaw rigor meat as well as in cold shortened meat is prevented up to a certain point due to muscle attachment to the skeleton.

In addition, thaw rigor can be prevented by several methods, such as by allowing onset and resolution of rigor mortis at 14°C to 16°C, by suspending the carcass in altered positions such as pelvic suspension, or by ES (Prändl and others 1994).

ATP’s, being the fuel for muscle contraction, presence allows contractile proteins to polymerize from actin + myosin to actomyosin. Protein polymerization means sarcomere reduction and, consequently, muscle toughening. During onset of rigor mortis, ATP depletes to ADP and finally IMP (inosinmonophosphate); this chemical species is not able to supply energy for polymerization; therefore, rigor mortis occurs when ATP is fully converted into IMP (Prändl and others 1994). ES fully depletes ATP to IMP, thus no energy is supplied for protein polymerization, hence for muscle contraction. In this situation, freezing does not affect meat tenderness as no further polymerization can take place (Savell and others 2005).

Studies reported by Kang and others (1983) in rabbit muscle subjected to ES using 50 mA showed changes in myofibrillar proteins. Once actin and myosin polymerize to actomyosin during contraction, this complex is dragged toward the meromyosin fraction of the main myosin helix; however, meromyosin also posses ATPase activity; when the actomyosin complex is at the meromyosin ATPase region, actomyosin splits into actin and myosin, and relaxation takes place. These authors reported a decrease in ATPase activity of ES-treated muscles. However, activity slowly increased during the 7 day storage. Actomyosin dissociation of ES muscles was lower than in vivo muscles; the authors conclude that ES minimized actomyosin changes.

Protein molecular mass, as analyzed by SDS-PAGE, showed pH 6.37 for nonstimulated and pH 6.01 for stimulated myofibrils of Bos indicus crossbred cattle. It was also found that muscle appearance improved, although no considerable degradation of I-band proteins occurred (titin, nebulin, desmin, and troponin-T) (Ho and others 1997). These authors also mention that the increase in tenderness is not a result of protein structural proteolysis of the Brahman and Simmental bull’s (B × S) muscle tested. The most noticeable fracture frequency in electrically stimulated muscle I-bands suggested that it could be a factor associated to tenderness.

### 17.4 Meat Tenderness

Tenderness, together with color and juiciness, is one of the most important meat sensory characteristics. ES has been successfully used to improve tenderness and overall quality of meat, accelerating the tenderizing process during storage (Pospiech and others 2003; Acevedo 2004; Soria and Corva 2004).
Myofibrillar proteins and connective tissues constitute the structure of the meat. Connective tissue protein content varies between 2% and 6% in relation to total proteins. This difference is mainly caused by muscle type, species, and age of the animal, as well as the specific activity of a given muscle, although muscle metabolism depends on the animal genotype (Pospiech and others 2003). Solomon and others (1986) studied the effect of ES on 78 pure bred young bovine carcasses (10–18 month Angus and Brahman, ES for 2 s at 550 V, 1.5 A, 20 pulses); loins were sensory evaluated for tenderness. The panel found a significant increase in tenderness and decrease in toughness due to connective tissue.

Meat reaches pH values around 6.0 at 10–12 h postmortem; but this value is reached at 1–2 h postmortem in stimulated meat. ES meat shows intense muscular contractions, resulting in fast rate glycolysis and pH decrease. However, this abrupt decrease also influences the development of early rigor mortis, followed by rapid resolution that promotes a fast relaxation rate. At the same time, intracellular calcium is rapidly liberated; as a consequence, calpain activity and proteolysis rate are increased, improving the meat tenderness (Elgasim and others 1981; Warriss 2000; Soria and Corva 2004).

According to Pospiech and others (2003), protein breakdown during ripening results in increasing the meat tenderness. This is due to three factors (Hedrick and others 1994) related to muscle fiber behavior. First, due to cold shortening prevention by reducing rigor mortis slow phase, but accelerating further contraction. Second, due to calcium liberation by ES, myofibrillar proteolysis occurs as a result of calpain activation. Finally, myofibril fracture occurs due to extreme contractions caused by the electric current.

Improved tenderness can be obtained by a variety of methods including the use of enzymes, mechanical methods, and ES, with early onset of rigor mortis, decreasing the ripening time and producing brighter and more tender meat that is more acceptable in restaurants, hotels, and other hospitality businesses (Yanar and Yetim 2003; Soria and Corva 2004).

Ripening is usually carried out to improve meat sensory characteristics such as tenderness, flavor, and odor; ES application reduces the ripening time enhancing quality. Cross (1979; cited by Sams 1999) discussed ES tenderizing effect as a possible result of several facts. First, ATP depletion is accelerated, resulting in cold shortening prevention; it could be also due to a fast postmortem pH decrease while muscle temperature is still high (30–32°C), to increased endogenous proteolytic enzyme activity, or to the physical disruption on muscular fibers. Ripening-stimulated carcasses yield more tender meat than nonstimulated ripened carcasses. Yanar and Yetim (2003) studied 14 (3–5 years) mixed breed Western male ovine (black, white faced) by applying ES at 350 V for 45 s, 15 pulses at 1.5 s intervals on Longissimus dorsi and Semimembranosus muscles. Tenderness was analyzed by a trained panel, finding that the more tender samples were obtained from ES meat.

After 7 days ripening, stimulated meat obtained from 96 goats were more tender than nonstimulated meat (McKeith and others 1979). Studies by Zocchi and Sams (1999) on 7 week chicken ES carcasses (5 pulses, 450 V, 450 mA), stunned by head immersion in 1% NaCl and deboned after slaughtering, indicated that meat tenderness was equivalent to that in meat obtained 4 h after slaughtering, that is 50% time reduction to achieve the same tenderness. Similar results were reported by Kang and others (1991) on 14–16 week white Japanese female rabbits, stimulated immediately after slaughtering at low voltage (35–45 V, 50 mA max., 3 ms, pulses every 8 ms for 15 min) and at high voltage (200 V, 80–1000 mA max.). These authors suggested that penetration force increased with rigor mortis onset in ES muscles, this did not occur in muscles attached to bones.

Studies carried out by Castañeda and others (2005) on 54 female broilers, 1.5–1.6 kg, electrically stimulated at 450 mA, 450 V, 2 × 2 s, 7 pulses/s, showed that ES postmortem increases meat tenderness due to accelerated ATP loss, pH decrease, and muscular fiber physical disruption. The authors also reported onset of rigor mortis at 30–32°C; slow cooling may also cause pale color and water-holding capacity reduction. Normal final pH (5.9) meat, but showing PSE (pale–soft–exudative) condition was observed in meat stimulated after 3 h postmortem and subjected to slow cooling for 12 h (Elgasim and others 1981).

Zocchi and Sams (1999) and Castañeda and others (2005) pointed out that high voltage (450 mA, 450 V, 2 s × 2 s with 7 pulses) ES followed by rapid cooling (4°C) did not alter protein functionality or produce PSE meat. However, there is evidence that slow cooling after ES could negatively affect water-holding properties of the meat.
Soria and Corva (2004) and Savell and others (1977) studied the effect of ES on beef, lamb, and chevron. The two groups agreed that ES promotes postmortem glycolysis acceleration, causing the onset of rigor mortis in muscle fibers before cold shortening takes place, and significantly increasing sarcomere length. These observations were also reported by McKeith and others (1979) in chevron meat, showing 20% increase in Longissimus dorsi muscle tenderness, whereas nonconsistent results with respect to tenderness increase were observed in Biceps femoral and Semimembransus muscles. ES and slowly cooled (2°C for 24 h) Suffolk carcasses showed fast pH decrease in Longissimus dorsi muscle, as well as reduced cold shortening in the hemiapioneurotic muscle and increased tenderness in both muscles (Radish and others 1983). However, Elgasim and others (1981) reported no significant difference regarding sarcomere length between stimulated and nonstimulated beef carcasses, cooled at two different temperatures (2°C and 16°C).

Kerth and others (1999) reported the results obtained from 12 (90–120 days) lamb ES carcasses (Hampshire × Rambouillet, 59 kg). One side of each carcass was randomly assigned to an ES treatment of 550 V and 60 Hz of electricity for 2 s on and 2 s off 15 times. The authors concluded that stimulated meat showed a bright red color, fast pH decrease, no effect on myofibril fragmentation index, and sarcomere length was not affected in general with the exception of sarcomere length reduction in Triceps braquial muscle. Similar observations on sarcomere length in ES muscles were reported by Savell and others (1978). In addition, studies by Bouton and others (1978) carried out with male bovine (2–4 years, 150–180 kg, subjected to ES at 110 V maximum voltage), and later stored for 22–24 h, showed that low voltages can prevent the negative effects associated with rapid cooling or hot deboning. Conversely, Davel and others (2003) reported that stimulated meat was considerably less tender than the nonstimulated samples, since the ES was carried out at low voltage (20 V, 45 Hz, for 45 s). The results show that ES had an effect in reducing tenderness suggesting that ES could be applied to meat obtained from old animals to reduce variation in tenderness due to age, breed, species, slaughtering method, and nutritional factors.

Results obtained by Craig and others (1999), on 72 electrically stunned broilers, and later stimulating the carcasses, showed that stunning and stimulation significantly affect blood loss, pH decrease, and sarcomere length increase; stimulation at 440 V accelerates the rigor mortis onset. The results reported by these authors agreed with previous reports of Savell and others (1977) regarding sarcomere length.

The effect of sex was studied by Zywica and Katarzyna (2003). These authors studied 18 month heifers and bulls. ES was carried out on the left carcass half at 330 V, 17 Hz, 0.9 pulses for 120 s. The right half was the control. Twenty-four hours after stunning, the hemiapioneurotic muscle was separated from the carcass and divided into 1 kg sections. Sensory and instrumental analysis showed that high-voltage ES effect on cooked meat depends on the sex of the animal. Better meat quality was obtained from ES heifer hemiapioneurotic muscle.

Marination is a process whereby meat is subjected to salts affecting the electronic environment of muscle fibers or activating specific enzymes, such as calpains, and modifying the meat texture. Young and others (2004) studied the effect of ES on 93 poultry breasts marinated with polyphosphates. ES was applied in pulsed current, 220 V alternating current for 90 s, 0.5 s on followed by 1 s off. pH rapidly decreased and sodium tripolyphosphate absorption was increased; water loss after cooking was not affected. The same group (Young and others 2005) analyzed the force required to cut the Pectoralis major muscle of 40 (52–56 days) broilers electrically stimulating the carcass for 90 s with 220 V, 132–140 mA per carcass; after evisceration the carcass meat was cooled for 3 h on ice. Less force was required in stimulated meat; higher yields were obtained after cooking.

17.5 Effect of ES on Bacterial Growth

A major worldwide concern is meat sanitation when a specific process is applied. Several studies have been carried out regarding microflora present in the ES meat. Kotula and Emswiler-Rose (1981) studied the relationship between cut grades, hot or cold deboning, ES, and bacterial incidence in 10 American beef cuts. The authors reported that there was no effect of hot or cold deboning or ES in the growth of aerobic bacteria.
Butler and others (1981) analyzed microbial populations and pH in ground meat from Biceps femoral and Infraespinatus muscles of 279–378 kg bovines. The meat was previously inoculated with Lactobacillus spp., Pseudomonas spp., Acinetobacter sp., Brochothrix thermosphacta, Erwinia herbicola and Moraxella sp., and stimulated (550 V, 16 pulses at 1.8 s intervals). Inoculated and noninoculated samples with and without ES were analyzed for the same bacterial populations. Although pH was significantly reduced by ES, no significant differences in bacterial populations were observed between ES and nonstimulated meat. However, Guerrero and others (2004) point out that there is lower bacterial growth in ES meat, due to the fact that lactic acid content, which results in a rapid pH decrease, creates an unfavorable environment for the development of microorganisms. It can be concluded that ES has no influence on bacterial proliferation in meat; pH decrease is due to ES as discussed before and not due to the presence of lactic acid.

### 17.6 Implications

ES has been reported as an efficient technique to improve meat quality, especially tenderness in various animal species. However, it involves several complex technological factors to be controlled for being successful. This technique is mainly attributed to glycolysis acceleration, preventing excessive muscular fiber shortening. As onset and resolution of rigor mortis is accelerated in ES carcasses, it allows refrigeration, or even freezing processes, to be applied just after slaughtering and cleaning, and the processing time is considerably reduced. On the other hand, as the technique reduces the processing time and labor, it also represents employment loss when applied in developing countries, where more employment is necessary.

## REFERENCES


