

Effects of Electrical Stimulation on the Functional Properties of Lamb Muscle

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ABSTRACT

One side from each of eleven lamb carcasses was electrically stimulated (60 Herz alternating current at 240v followed by 420v) within 45 min postmortem. Three carcasses (stimulated and respective control sides) were rapidly chilled (1°C), three carcasses received a delayed chill (12°C until pH 6.0 was attained, then excision and 1°C), and three carcasses were slowly chilled (12°C). Measurements beginning at 44 hr postmortem showed that stimulation increased the sarcomere lengths but had few consistent or significant effects on water-holding capacity, protein solubility, emulsifying capacity, gel strength, cooking loss, or binding strength. The remaining two carcasses were rapidly chilled and their meat was manufactured into frankfurters. The emulsion stability was slightly improved by stimulation but smokehouse weight loss, Warner-Bratzler shear force, penetration force, cooking loss, and sensory characteristics were unaffected.

INTRODUCTION

ELECTRICALLY STIMULATING a carcass immediately after slaughter accelerates the postmortem glycolysis rate (Smith et al., 1977; Cross, 1979), which continues even after the cessation of the electrical stimulation (Bendall, 1976). Stimulation does more than accelerate aging and revert cold shortening (McKeith et al., 1979). Stimulation increases tenderness, promotes a more rapid development of marbling, increases muscle firmness, brightens muscle color, decreases USDA maturity score, reduces heat ring development, and produces no deleterious changes in palatability or the appearance of meat held under retail conditions (Smith et al., 1977; Savell et al., 1978a, c; McKeith et al., 1979; Hall et al., 1980; George et al., 1980; Riley et al., 1980). The growth of spoilage bacteria is unaffected by electrical stimulation (Gill, 1980). Electrical stimulation permits earlier cutting, chilling, or freezing of meat without loss of quality.

All studies on electrical stimulation to date, however, were on the properties of intact muscle, but trimmings and some skeletal meats from animals stimulated to accelerate chilling and boning will also be used in processed meat products. This study was undertaken to determine the effect of electrical stimulation on the functional properties of the meat and meat products. Lamb was used in this study because it shows the same general biochemical and physical responses as other meats (Carse, 1973; Bendall, 1976; Chrystall and Hagyard, 1976; Savell et al., 1977; Bowling et al., 1978) and it is lower in cost per carcass and easier to handle than beef carcasses.

MATERIALS & METHODS

Animals and stimulation

Nine lambs were slaughtered, dressed, and split at a local commercial facility. One side of each carcass was stimulated with a hog stunner (Best and Donovan) that had lead wires and 5 in. stainless

steel pin electrodes attached to the normal electrodes (Savell et al., 1977, 1978b; McKeith et al., 1979). One pin electrode was placed into the gastrocnemius muscle and the other into the muscles between the shoulder blade and spinal column. Each stimulation-relaxation cycle consisted of 60 Hertz alternating current on for 5 sec and off for 5 sec. After 12 cycles at 280v and 24 cycles at 420v the muscles had ceased twitching. All stimulations were completed within 45 min of slaughter.

Chilling treatments

The untreated and stimulated sides were then assigned to slow chill, delayed chill, or rapid chill treatments. Those designated for rapid chilling were packed in ice for the 20 min drive to the laboratory. At the laboratory, slow chill carcasses were hung in a room at 12°C (82% relative humidity) for 20 hr postmortem when they were boned and the meat was stored at 1°C (92% relative humidity). Delayed chill carcasses were hung in a room at 12°C until the pH declined to 6.0 which required an average of 2 hr for the stimulated and 10 hr for the control sides. The meat from the delayed chill carcasses was then excised and stored at 1°C. The rapid chill carcasses were taken out of the ice and hung in a cooler at 1°C for 20 hr postmortem and boned.

Temperature, pH, and ATP analyses

The interior temperatures of the longissimus dorsi (LD) muscles were measured with a temperature probe (Yellow Springs Inst. Co.) in one side of each animal before stimulation and then in both sides at 2, 4, 8, and 20 hr postmortem. The pH values of the LD were determined at the same times by the iodoacetate slurry method (Cassens and Newbold, 1967b). Samples of the LD for adenosine triphosphate (ATP) analyses were also excised before stimulation and at 2, 4, 8, and 20 hr postmortem, frozen in isopentane precooled to -160°C and stored in liquid nitrogen. The ATP assay was based on the procedure of Busch et al. (1967) with the modification of preparing the muscle extract by homogenization with a Brinkmann Polytron homogenizer and diluting the ether-washed filtrate to 25 ml with pH 7.4 buffer (1.00 mM EDTA, 10.0 mM MgSO₄ and 100 mM 3-(N-morpholino)-propanesulfonic acid (MOPS)). Dissected firefly lantern tails or firefly lantern extract (Sigma Chemical Co.) were ground in the above buffer in a Teflon-glass homogenizer to extract luciferin-luciferase. This extract was centrifuged at 27,000 × G for 30 min (5°C), filtered through a 0.45 μm Millipore filter, held at 0°C, and used the same day. Ten microliters of each ATP standard or muscle extract were added to 100 μl luciferin-luciferase solution, and the ATP content was measured from the bioluminescence at 25°C (DuPont model 760 Luminescence Biometer).

The sarcomere lengths of samples of the LD taken at 44 hr postmortem and fixed in 2% glutaraldehyde (pH 5.7) for 24 hr were determined by laser diffraction (Ruddick and Richards, 1975).

Functional property tests

The water-holding capacities of LD muscles ground at 44 hr postmortem were determined by the saline method (van Eerd, 1972) and press method (Wierbicki and Deatherage, 1958). For measuring protein solubilities, the muscles were blended as follows: in 0.05M phosphate buffer (pH 7.4) for sarcoplasmic proteins, in 1.1M KI and 0.1M phosphate buffer (pH 7.4) for total soluble proteins (Borchert and Briskey, 1965), and in unbuffered 3% NaCl for myofibrillar proteins. After the samples were blended, they were centrifuged and the soluble proteins were assayed by the Biuret reaction. The shrink losses during cooking of the ground lamb were determined by molding uniformly shaped 100g patties and broiling them until they were well done. This required 7 min for the first side and 5 min for the second, they were then reweighed

and the losses were calculated.

For determining the emulsifying capacities (Swift et al., 1961), 15g ground LD in 45 ml cold 1M NaCl were blended at high speed (Servall Omni-mixer with rheostat). Three grams of this slurry were mixed with an additional 50 ml cold 1M NaCl; 40 ml of vegetable oil (Wesson Oil) at ambient temperature were added. An emulsion was formed by blending at medium speed for 15 sec; then oil was added while the mixing continued at high speed until electrical resistance measurements showed that the emulsion had broken (Webb et al., 1970). The total volume of oil emulsified by the 0.75g of meat was recorded. The remaining slurry was spooned into two 40 ml beakers and heated in a water bath at 70°C for 10 min. The gels were immediately cooled on ice and stored at 5°C. The force required to penetrate the gels was measured with the Gel Tester (Marine Colloids, Inc.) with an 11 mm diameter plunger.

The binding strength of the salt soluble proteins (Pepper and Schmidt, 1975) was measured on the postrigor muscles from the leg which were trimmed of excess fat and connective tissue, and hand cut into 1 cm cubes. These cubes (500g) were mixed with 50 ml water and 12.5g NaCl in a Hobart mixer (model N-50) with a dough paddle for 15 min. The resulting tacky mixture was stuffed into 5 cm casings, cooked to an internal temperature of 71°C in a convection oven at 110°C, and immediately cooled in an ice slush. To measure the binding strength of this solidified mixture, it was cut into 2.5 cm sections, warmed to ambient temperature, and placed with the flat surfaces on the platen of an Instron Universal Testing Instrument. A rounded 0.64 cm thick blade forced through the section at 100 nm/min compressed and stressed the sample until the binding between the meat pieces failed. The force exerted at the point of failure was recorded as the binding strength.

Frankfurter manufacture

Two additional lambs were slaughtered and split. One side from each was stimulated and all sides were rapidly chilled. The pH values and temperatures were followed as previously described. The LD and leg muscles were excised at 20 hr postmortem and ground, and the protein, fat, and moisture content of these were determined by the Kjeldahl, soxlet, and oven drying procedures, respectively (AOAC, 1975). The proximate analysis of fresh pork back fat obtained from a local processor was also determined. Frankfurters were formulated to contain 11% protein and 19% fat as follows: 700 g lean lamb, 269g pork fat, 269g ice, 23.2g NaCl, 14.8g sugar, 14.8g spice, 0.12 NaNO₃, and 0.20g Na ascorbate. The lean lamb, dry ingredients and half of the ice were chopped for 2 min in a small silent cutter (Hobart 84145) that had been modified to have four cutting blades instead of two. The fat and remaining ice were added and chopping was continued until the temperature reached 15.5°C, which required an average of 7 min 20 sec. The emulsion was studded into a 25 mm casing, cooked with smoke in an air-conditioned smokehouse to an internal temperature of 71°C, and immediately cooled with a water shower. The frankfurters were stored at 1°C until analyzed.

The stabilities of the raw emulsion were determined by the procedure of Meyer et al. (1964). Weight losses during the smokehouse cooking were measured. Weight changes in the finished frankfurters after they were boiled in water 10 min also were evaluated (Tauber and Lloyd, 1947). The Warner-Bratzler shear force and the penetration force were measured on the Instron Universal Testing Instrument with the crosshead moving at 100 mm/min. For the penetration force measurement, an 8 mm diameter rod was moved through a cross-section of 2.5 cm long piece of frankfurter, avoiding the skin, which has an important effect with the Warner-Bratzler shear force.

Triangle tests were conducted in taste panel booths under green lighting. The panelists were asked to distinguish by texture or possibly flavor differences between frankfurters made from the stimulated and control meats. The frankfurters were placed in boiling water and the water was reheated to boiling. The frankfurters and water were removed from the heat and allowed to stand for 10 min. The samples were kept warm on a steam table until presented to an experienced panel.

Statistical analysis

The data for each test and chill treatment were analyzed by a two-way analysis of variance with the animals one factor and presence or absence of stimulation the other. This design utilized the pairing of the control and stimulated sides for each animal.

RESULTS & DISCUSSION

Electrical stimulation effects on muscle biochemistry

Electrical stimulation effectively lowered the pH values (Fig. 1) and the ATP concentrations (Fig. 2) in the LD muscles. The average pH of the stimulated sides from all chilling treatments had declined to 6.0 when measured at 2 hr postmortem, while the pH values for the control sides averaged 6.6 and required 10-13 hr to reach pH 6.0. Carse (1973) found that stimulating lamb with 250v caused the pH to decline to 6.0 in approximately 3 hr; Chrystall and Hagyard (1976) reported that 3,600v reduced the pH to 6.0 in less than 1 hr. In unstimulated sides, the pH of the rapidly chilled LD muscles declined at the same rate as the slow or delayed chill LD muscles. The final pH values for the stimulated and control sides were all between pH 5.6 and 5.8.

ATP concentrations also fell very rapidly in the stimulated sides, while the concentrations in the control sides

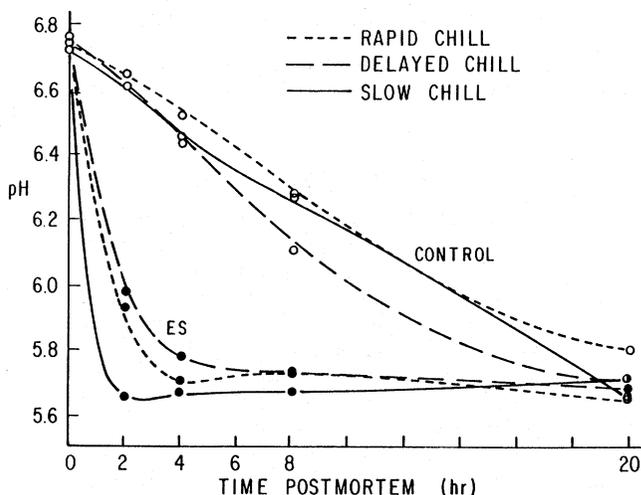


Fig. 1—Decline of pH in electrically stimulated and control sides of lamb carcasses held under different cooling treatments. Each point represents the mean of three animals: ○, control; ●, electrical stimulation.

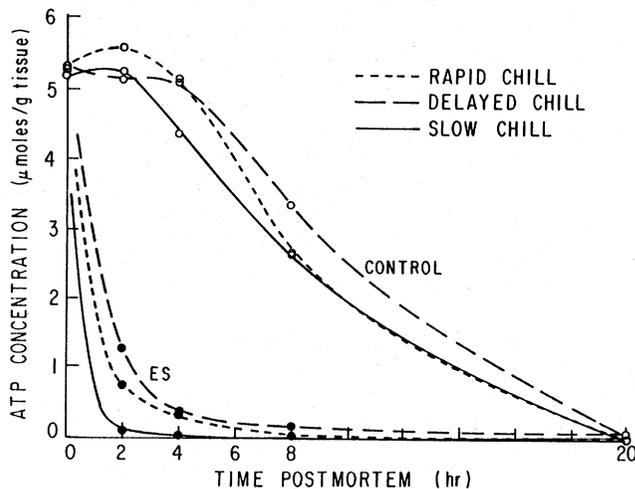


Fig. 2—Decline of ATP in electrically stimulated and control sides of lamb carcasses held under different cooling treatments. Each point represents the mean of three animals: ○, control; ●, electrical stimulation.

changed very little until 4 hr postmortem. There were no differences between the temperature treatments in the unstimulated sides; however, this comparison also included between animal variations. Other workers have also found little differences in pH or ATP declines between 1 and 15°C storage of isolated strips of beef muscle (Cassens and Newbold, 1966, 1967a, b; Newbold and Scopes, 1967; Follett et al., 1974) or lamb (Bowling et al., 1978). Cold shortening can occur at 1°C without an accelerated pH or ATP decline (Cassens and Newbold, 1966). The temperatures of the interior LD of both rapidly chilled and electrically stimulated, delayed chill muscles were below 10°C after approximately 5 hr (Fig. 3). The delayed chill control muscles reached pH 6.0 at 10 hr, when they were excised and placed in the cooler at 1°C. They reached 10°C after 11 hr. The slow chill sides were held at 12°C and reached 14°C at 8 hr.

The sarcomere lengths of the LD at 20 hr postmortem of each treatment group were significantly ($p < 0.05$) longer in the stimulated sides (Table 1). Longer sarcomeres were reported by Bouton et al. (1978) and George et al. (1980)

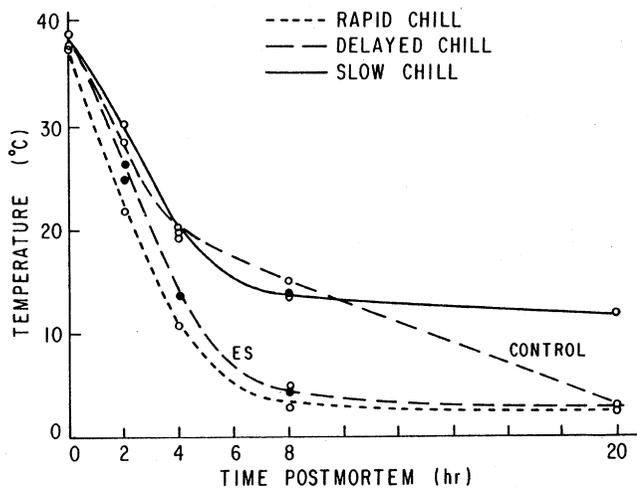


Fig. 3—Longissimus dorsi temperatures of electrically stimulated and control sides of lamb carcasses held under different cooling treatments. Each point represents the mean of three animals: ○, control; ●, electrical stimulation.

but were not observed by Savell et al. (1977, 1978a), Westervelt and Stouffer (1978), McKeith et al. (1979), or Will et al. (1979). Savell et al. (1978a) and Will et al. (1980) showed that electrically stimulated meat had bands of sarcomeres that were supercontracted and others correspondingly stretched. We do not know why our sarcomere lengths were shorter than those reported by the papers cited above. The cause would not be the laser technique because Westervelt and Stouffer (1978) and George et al. (1980) found few differences between microscopic and laser measurements of sarcomere length in either control or electrically stimulated muscle.

Electrical stimulation effects on protein functionality

The effect of stimulation on water-holding capacity was inconsistent and generally minimal. In the slow chilled carcasses, nonsignificant differences in water-holding capacity were found between stimulated and control sides with the press method, while a significant ($p < 0.05$) increase was produced by stimulation when measured with the saline method. Stimulation of the delayed chill sides decreased free water determined by the press method but had no effect on saline water-holding capacity. In the rapidly chilled stimulated carcasses, the free water increased nonsignificantly, and the saline water-holding capacity decreased significantly ($p < 0.05$). Wierbicki and Deatherage (1958) reported approximately 51% free water in lamb leg, and van Eerd (1972) found the saline water-holding capacity of mutton to be 140% immediately postmortem, suggesting that the water-holding capacity of all of our samples was good. No influence of electrical stimulation was found on expressible juice in porcine longissimus (Westervelt and Stouffer, 1978) or on drip losses in bovine longissimus and semitendinosus (George et al., 1980). When the ground meat patties were broiled, cooking losses were mostly water because the meat patty was formed from lean meat. All losses were on the order of 35-40% and stimulation had no significant effect. Electrical stimulation was reported either to have no effect (Savell et al., 1978b) or to increase cooking losses (Savell et al., 1978c) of beef steaks.

The solubilities of the muscle proteins in any of the three extracting solutions were not changed by the electrical stimulation or chilling treatments. George et al. (1980) claimed electrical stimulation caused sarcoplasmic proteins to denature onto the fibrils to produce the irregular bands observed under the microscope. These bands have

Table 1—Functional properties of lamb from electrically stimulated and control sides that were held under different cooling treatments^a

Chilling treatment	Sarcomere length (μ)	Water-holding capacity		Shrink loss (%)	Soluble protein (mg/g)			Emulsifying capacity (ml oil/.75g)	Gel strength (g)	Binding force (kg)
		Press (% free water)	Saline (%)		Sarcoplasmic	Salt	Total			
Slow chill										
Control	1.51	51.5	166	39.4	52.8	62.3	87.0	92.5	48.7	7.0
Stimulated	1.77	56.0	195	35.0	55.6	60.2	96.0	97.7	55.9	7.3
	**	ns	**	ns	ns	ns	ns	*	ns	ns
Delayed chill										
Control	1.22	59.3	159	38.2	53.2	60.8	95.1	98.8	64.3	5.8
Stimulated	1.49	50.2	167	36.8	53.0	62.4	87.9	93.5	49.1	5.3
	**	*	ns	ns	ns	ns	ns	ns	**	ns
Rapid chill										
Control	1.30	45.0	186	38.8	56.2	60.8	90.6	95.6	60.9	5.8
Stimulated	1.45	52.3	166	37.9	55.0	59.6	82.2	93.2	48.2	6.2
	**	ns	*	ns	ns	ns	ns	ns	ns	ns

^a The values are means from three animals, each value was determined in triplicate for each animal except for the sarcomere length ($n = 20$), emulsifying capacity and gel strength ($n = 4$), and binding force ($n = 6$); ns = not significant

* ($p < 0.05$)

** ($p < 0.01$)

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also been interpreted as supercontracted sarcomeres by Savell et al. (1978a) and Will et al. (1980). Our data showed that if protein precipitation did occur, it did not affect protein solubility. The emulsifying capacity was slightly increased ($p < 0.05$) by electrical stimulation of the slow chilled muscle, but the slight decreases observed in the other temperature treatments were not significant. The absence of a major change in emulsifying capacities further implied that stimulation did not cause an irreversible reduction of myofibrillar proteins' ability to emulsify fat.

A significant difference ($p < 0.05$) in the gel strength was found between the stimulated and control delayed chill meat, although no significant differences were observed with the stimulation for the other chilling treatments. In the binding strength experiment, no significant differences were detected between meat from stimulated and control sides with any chilling treatments. These tests depended on the myofibrillar proteins' ability to be extracted, solubilized, and then heat denatured to form the gel or to bind intact meat pieces. The gel strength and binding strength data agree with the earlier results that electrical stimulation does not have a consistent influence on the proteins.

Electrical stimulation effects on frankfurter qualities

Meat from two additional animals were used for making frankfurters. All sides were packed in ice at the abattoir and rapidly chilled. The emulsion stability test showed that the emulsions made from the stimulated sides had significantly less ($p < 0.05$) total fat and water losses than those from the control sides (Table 2). However, the values indicated that all the emulsions were extremely stable (Meyer et al., 1964). The smokehouse losses of frankfurters made from stimulated and control muscles were identical. When tested with the Instron, both penetration and Warner-Bratzler measurements also showed no differences between frankfurters made with stimulated or control meat. The cook test of boiling for 10 min showed that emulsions from treatments were extremely stable; the slight losses were not significantly different. Most significant, the sensory panel was unable to differentiate between frankfurters made from the control and stimulated meat, the panelists made only 13 correct judgments of 34 trials ($p > 0.05$) in the triangle test.

A very limited decline in pH occurred in one carcass; the 20 hr postmortem control side had a pH of 6.7 and the stimulated side pH 6.6, whereas the pH values in the other carcass were 5.9 and 5.7, respectively. The meat with the limited pH decline had less fat and water exudate measured with the emulsion stability test than normal meat from both control and stimulated sides. Frankfurters made from the meats with higher pH lost weight during boiling while frankfurters made from the normal meat gained weight. Neither difference was of practical importance, and the

Table 2—Physical characteristics of emulsions and frankfurters made from electrically stimulated and control sides of lamb carcasses that were rapidly chilled^a

	Emulsion stability (ml exudate/25g)	Smoke-house loss (%)	Penetration force (g)	Warner-Bratzler shear (kg)	Cook test (% loss)
Control	0.52	9.8	397	1.7	0.09
Stimulated	0.21	9.8	402	1.7	0.02
	*	ns	ns	ns	ns

^a The values are means from two animals, the number of replicates within each animal were emulsion stability ($n = 3$), smokehouse loss ($n = 2$), penetration force and Warner-Bratzler shear ($n = 10$), and cook test ($n = 3$); ns = not significant.

* ($p < 0.05$)

other tests revealed no distinctions. In the triangle test between control and stimulated meats there were six correct of 15 judgments for normal meat and seven of 19 for the frankfurters made from meat with high pH, neither significant.

These experiments were designed to find effects from electrical stimulation on protein functionality and processing characteristics equivalent in magnitude to the declines in pH values and ATP concentrations or to the increases in tenderness in fresh meat. The data strongly suggest that there were no large beneficial or detrimental effects in lamb muscle. There may be a trend toward improved functionality in meat from carcasses chilled more slowly after electrical stimulation which could be shown to be significant by a larger experiment with more animals. However, we found that variation between animals was more likely to be significant than differences between control and stimulated sides. Pooling the animal means of all three chilling treatments ($n = 9$ animals) and conducting a paired t-test between stimulated and control sides for each of the functional characteristics on Table 1 showed significant differences only for the sarcomere lengths.

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