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Effects of Electrical Stimulation and Delayed Chilling of Beef Carcasses on Carcass and Meat Characteristics

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ABSTRACT

A 2×2 factorial experimental design with 2 replications was used to study the effects of a combination of electrical stimulation and delayed chilling of carcass on meat characteristics. Twenty Standard or Good grade beef cattle were slaughtered and 10 sides were assigned to each of the 4 treatments. Meat characteristics were evaluated subjectively (sensory panel evaluation) and objectively (W-B shear device). Electrically stimulated carcasses cooled faster in the first hour postmortem; thereafter the order of further cooling was reversed. The 24 hr postmortem weight loss in the electrically stimulated with delayed chilling did not differ ($P > 0.05$) from those receiving electrical stimulation plus immediate chilling nor those not stimulated but chilled immediately. For delayed chill carcasses, 24 hr postmortem weight loss was lower ($P < 0.05$) in electrically stimulated than in nonstimulated groups. Electrical stimulation reduced ($P < 0.05$) cooking losses. The difference in sarcomere lengths among the 4 treatments was not significant ($P > 0.05$). At the microstructural level, an open triad and T-system were observed immediately following electrical stimulation. As early as 24 hr postmortem, considerable Z-line degradation was observed in the electrically stimulated and delayed chilled samples.

INTRODUCTION

DEVELOPMENT of cold shortening upon immediate chilling (0–2°C) of pre-rigor muscle has been shown to increase beef muscle toughness (Locker and Hagyard, 1963). Since the recognition of this fact, several tenderization techniques have been suggested to avoid cold shortening and/or improve meat tenderness.

Excised pre-rigor muscles aged at 16°C for 2 days were more tender than those aged in the conventional manner (Busch et al., 1967). Also meat from beef carcasses held at 16°C for 12–20 hr immediately after slaughter was significantly more tender than meat from carcasses held at 2°C (Smith et al., 1971). These studies demonstrate that delayed chilling improves meat tenderness. Prevention of cold shortening was cited as the primary reason for the observed increase in meat tenderness when carcasses are chilled at elevated temperatures.

Some of the factors conducive to cold shortening are greatly reduced by electrical stimulation treatments. Low pH and ATP levels following electrical stimulation of beef (Bendall et al., 1976; Davey et al., 1976; Will et al., 1979) and lamb (Chrystall and Hagyard, 1976) have been reported. Low voltage, 2.5–45v, (Bouton et al., 1980; Taylor and Marshall, 1980) or high voltage in the order of 250–3600 V (Chrystall and Hagyard, 1976; Davey et al., 1976; Bendall et al., 1976) have been effective in improving meat tenderness.

Many investigators have utilized a single technique to improve meat tenderness and/or to prevent cold shortening. A combination of the hip-free suspension method and elevated temperature resulted in more tender beef muscles than either of the treatments alone or the aging of beef in the traditional way (Hostetler et al., 1975).

The objective of the current study was to compare the combined effect of electrical stimulation and delayed chilling (at 16°C for 12 hr) on some biochemical, organoleptic and histological traits of bovine muscles.

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EXPERIMENTAL

TWENTY U.S. Standard or Good grade beef cattle, with live weights ranging from 459–510 kg, were slaughtered at Oregon State University Meat Science Laboratory. Immediately after slaughter, the carcasses were skinned, eviscerated and split. One side of each carcass was electrically stimulated with 600v, 7 amp and 60 Hz for 1 min. A total of 20 sides was stimulated while the corresponding 20 sides were unstimulated, with 10 sides assigned to each of the treatments described in Table 1.

Sample pH was measured with a probe-type combined electrode inserted in the longissimus muscle (LD). The temperature was measured with an electronic digital thermometer inserted to about 40 mm in the center of the LD at the 13th thoracic vertebrae. Both parameters were recorded initially following carcass splitting and electrical stimulation and at 1, 2, 3, 4, 6, 12, and 24 hr postmortem.

Electron microscopy

Immediately following experimental treatments and at 24 hr postmortem, samples were taken from the LD muscle at the 2nd lumbar vertebrae and placed in sodium cacodylate buffered glutaraldehyde fixative. At this stage small fiber bundles were teased from larger muscle pieces to speed penetration of the solution and to assure sectioning. After fixation, samples were washed in fresh buffer, osmified, dehydrated with acetone, stained with a saturated solution of uranyl acetate, infiltrated and embedded with Spurr's epoxy resin. Sliver sections of longitudinally oriented fibers were cut using a diamond knife and Porter-Blum MT-1 Ultramicrotome, stained with lead citrate and examined in a Phillips EM–300 electron microscope.

Sarcomere length measurement

Sarcomere length measurements were made 72 hr postmortem on uncooked LD samples. Approximately 4g of muscle were blended with 35 ml of 0.25M sucrose solution for 30 sec at low speed in a Waring Blendor (Waring customer solid state 750). A phase contrast microscope equipped with filar micrometer was used to measure the length of 10 sarcomeres in each of 15 randomly selected myofibrils. Each mean of these measurements was taken to be the sarcomere length of the sample and expressed in micrometers (μm).

Cooking and taste panel tests

At 7 days postmortem, 3 steaks (each 3.5 cm in thickness)

Table 1–Treatment description

Treatment	Description
1. UNS+2°C	Unstimulated and held at 2°C for 7 days following slaughter.
2. ES+2°C	Electrically stimulated with 600v, 7 amp and 60 Hz for 1 min and held as in treatment 1.
3. UNS+16°C	Unstimulated and held at 16°C for 12 hr before transfer to 2°C for the balance of 7 days.
4. ES+16°C	Electrically stimulated as in treatment 2 and chilled as in treatment 3.

were removed from the rib-eye section (11–13th rib) of each side, wrapped in plastic-coated freezer paper and frozen at −18°C. Three frozen steaks per side were weighed, placed on broil pans (approx 15 cm from the flame) and broiled using 2 identical home-style gas ranges. All the steaks were cooked to an internal temperature of 70°C monitored with thermocouples (inserted into the center of each steak) attached to a recording potentiometer. The cooked steaks were weighed and 2 steaks randomly assigned for sensory panel evaluation and one steak was utilized for shear testing. A method similar to that described by Kennick et al., (1980) was used for Warner-Bratzler shear force measurement. For sensory panel evaluation the steaks were wrapped in aluminum foil, placed under an amber holding light until cut and served within 10 min after cooking. Each steak was cut into 5 serving portions with a given judge always receiving the same section from each sample. The same 10 judges served on all panels.

Cooking losses were taken as the difference between the weight of steaks before and after cooking and expressed in percentage.

Statistical analyses

A 2×2 factorial experimental design with 2 replications was utilized. Analysis of variance (Steel and Torrie, 1960) was used to determine the effect of treatments. Where significant F-values were obtained, the least significant difference (LSD) was calculated and used to determine significant differences among means.

RESULTS & DISCUSSION

THE RESULTS of pH and temperature measurements from immediately after slaughtering to 24 hr postmortem are presented graphically in Figures 1, 2 and 3. The pH and temperature at which muscles enter rigor mortis have pronounced effects on meat tenderness and other organoleptic properties (Parrish et al., 1969; Goll et al., 1964). Stimulated sides had a significantly ($P < 0.05$) lower pH following stimulation than did the control sides at the same time postmortem. However, a more rapid decline in pH of the control sides up to 24 hr postmortem resulted in no significant difference in pH between treatment groups at 24 hr postmortem. The average pH of the stimulated carcasses with delayed chilling and immediate chilling had dropped to 6.0 in 2 and 3 hr postmortem, respectively (Fig. 2). It is worth noting that the temperature at these times were 34.6 and 26.5°C, respectively. The nonstimulated carcasses chilled at 2°C had a temperature below 10°C when the pH was still above 6.0. Such a pH-temperature combination is very conducive to cold shortening and its effect could result in less tender meat.

In the 1st hr postmortem, electrically stimulated carcasses immediately chilled at 2°C, cooled faster than the control carcasses under the same chilling conditions, however, after that, the rate of cooling was faster in the latter treatment (Fig. 3). No explanation can be given at this

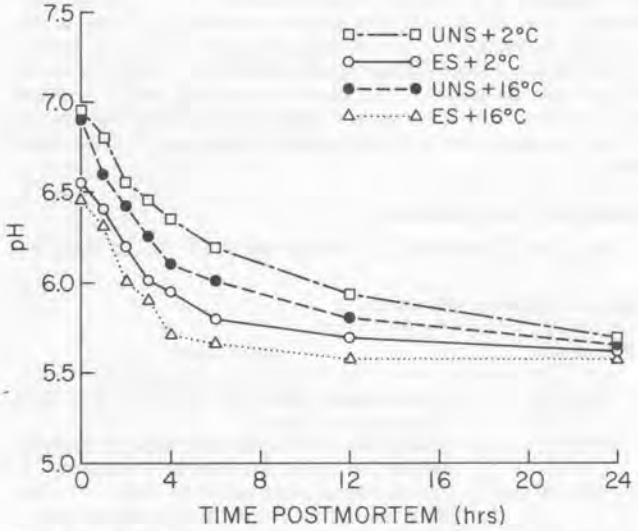

Fig. 1–Effect of electrical stimulation and carcass holding temperature on the rate of pH fall of beef longissimus muscle.

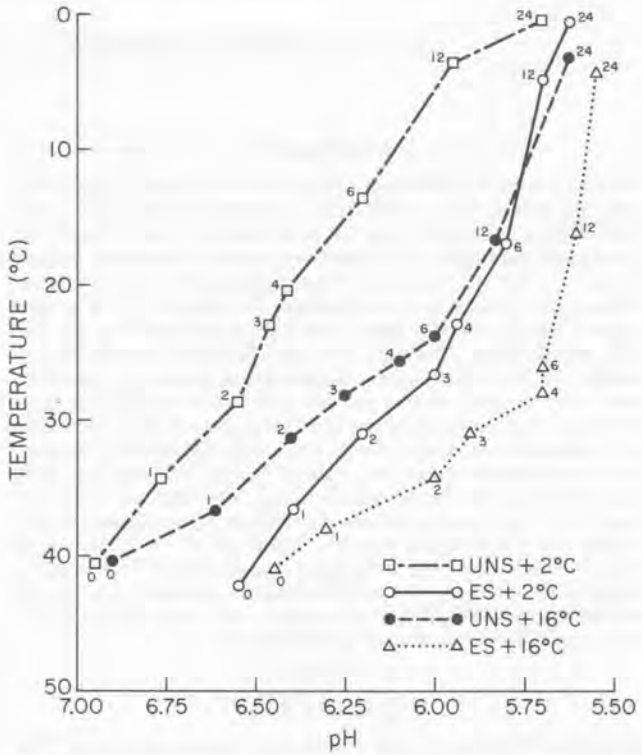

Fig. 2–Temperature-pH curve for beef longissimus muscle subjected to different treatments. Numbers on the curve points indicate hours postmortem.

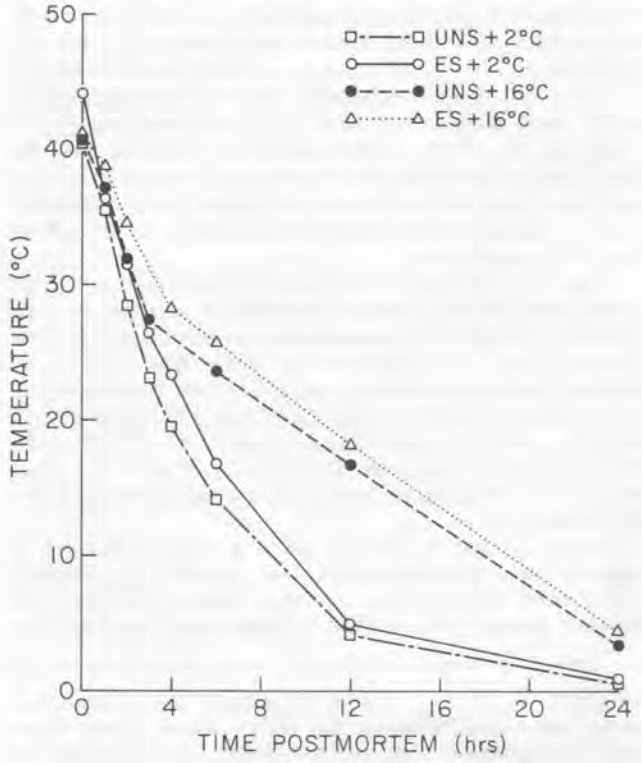

Fig. 3–Postmortem temperature course of longissimus muscle subjected to different treatments.

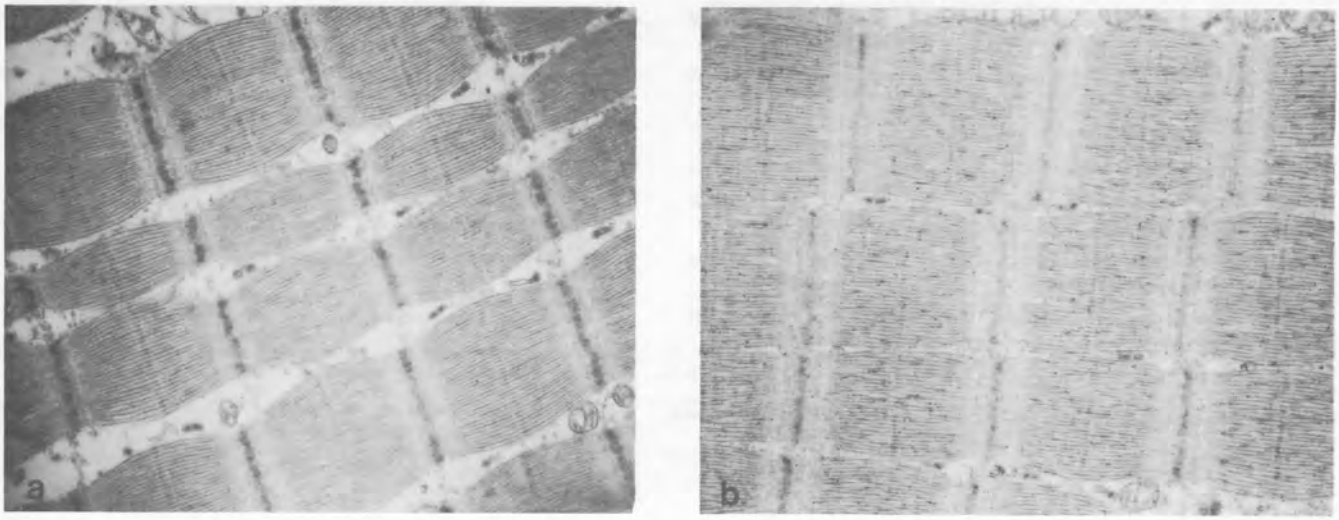

Fig. 4—Electron micrographs of longissimus muscle: (a) Sampled and fixed immediately after electrical stimulation (13,000x); (b) Unstimulated longissimus muscle sampled and fixed immediately after splitting of carcass (13,000x).

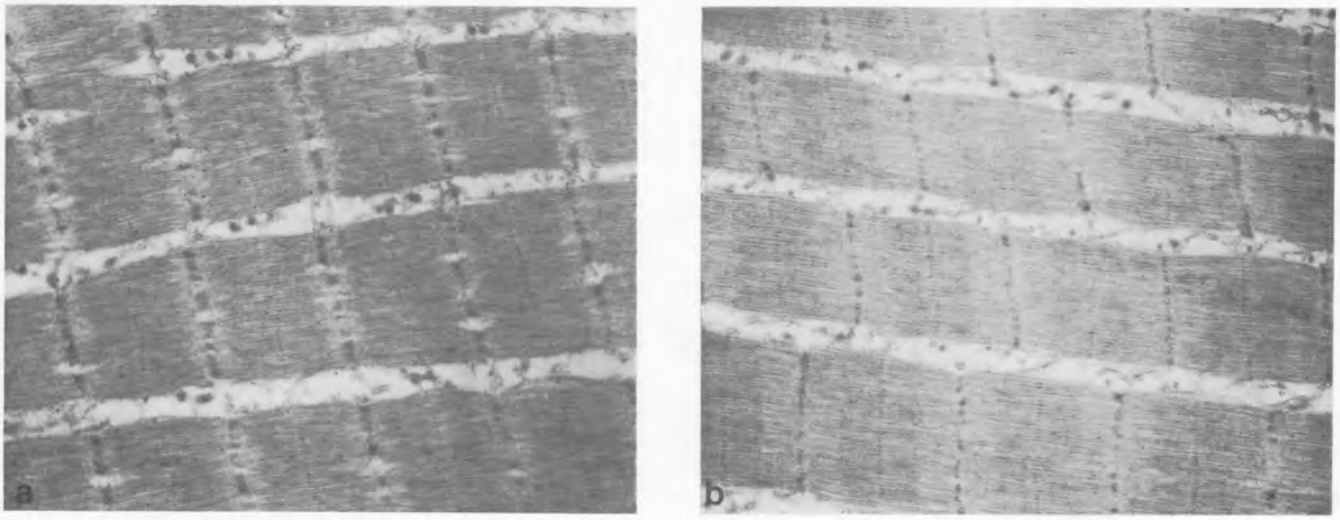

Fig. 5—Electron micrographs of longissimus muscle sampled and fixed 24 hr postmortem: (a) Stimulated sample aged for 12 hr at 16° C (13,000x); (b) Unstimulated sample aged for 12 hr at 16° C (13,000x).

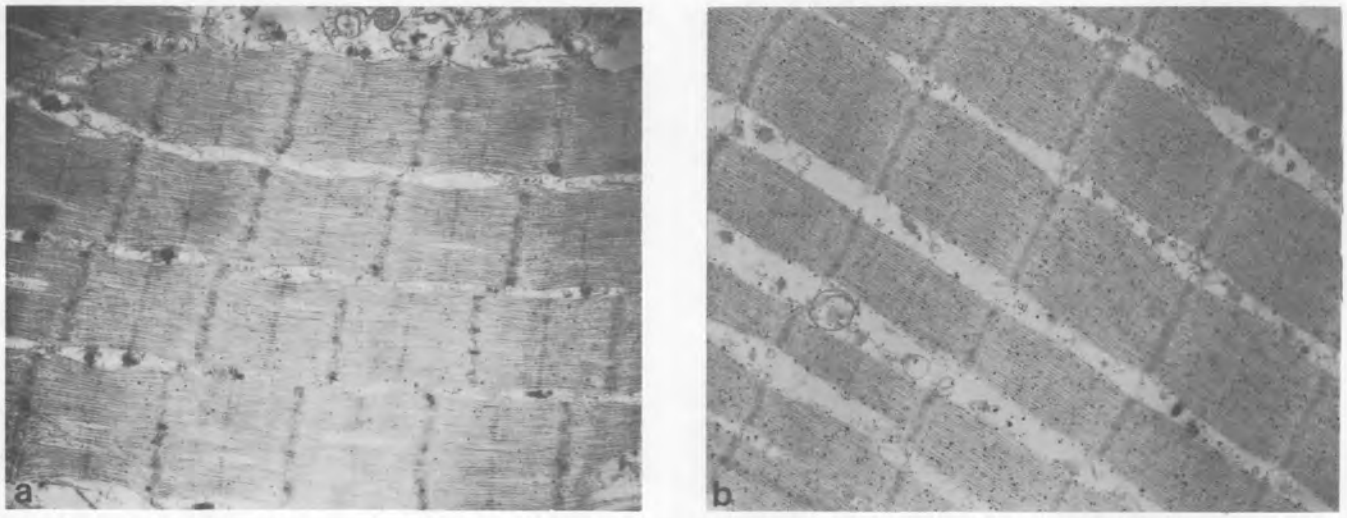

Fig. 6—Electron micrographs of longissimus muscle sampled and fixed 24 hr postmortem: (a) Stimulated sample aged at 2° C (13,000x); (b) Unstimulated sample aged at 2° C (13,000x).

Table 2–Chill shrink, cooking loss, sarcomere length and W-B values of beef loin steaks from carcasses subjected to different treatments

Item	Treatment[a]				LSD[e]	
	UNS+2°C	ES+2°C	UNS+16°C	ES+16°C	0.05	0.01
Chill shrink[b]	1.70	1.57	2.50	1.82	0.44	NS
Sarcomere length, μm	1.74	1.76	1.73	1.75	NS	NS
W-B, kg/cm^2 [c]	8.3	5.6	8.0	6.0	0.61	0.85
Cooking loss, %[d]	30.36	27.16	28.04	26.42	2.61	3.51

[a] See Table 1 for treatments
[b] Difference in hot carcass wt and 24 hr wt expressed as % of the hot carcass wt
[c] Mean of 10 carcasses per treatment with 6 observations per carcass
[d] Mean of 10 carcasses per treatment with 3 observations per carcass
[e] LSD = Least significant difference.

Table 3–Sensory panel evaluation of beef loin steaks from carcasses subjected to different treatments

Item[b]	Treatment[a]				LSD[c]	
	UNS+2°C	ES+2°C	UNS+16°C	ES+16°C	0.05	0.01
Aroma[d]	5.24	5.30	5.24	5.27	NS	NS
Tenderness[d]	4.03	4.81	4.36	4.84	0.63	NS
Juiciness[d]	4.75	5.06	4.73	4.67	NS	NS
Flavor[d]	4.84	5.12	4.91	4.81	NS	NS
Overall desirability[d]	4.35	4.89	4.62	4.54	NS	NS

[a] See Table 1 for treatments
[b] Values for each item based on an eight-point scale, desirability increasing with score
[c] LSD = Least significant difference.
[d] n/mean = 10j x 10 rep. = 100j/mean.

stage; however, Savell et al., (1979) observed an early muscle firmness in the favor of electrically treated carcasses. At 3 hr postmortem, the electrically stimulated group with delayed chilling for 12 hr had a pH of 5.9 and a temperature of 31.5°C (Fig. 2). These conditions are very conducive to pale, soft, exudative (PSE) meat; however, none of the carcasses in the present study had PSE muscle.

The unstimulated delayed chill group had a significantly ($P < 0.05$) higher chill shrink than all other treatment groups (Table 2). The electrically stimulated delayed chill group had a significantly lower chill shrink than the unstimulated delayed chilled group and did not differ significantly ($P > 0.05$) from the two groups which were immediately chilled. These results differ from those reported by Smith et al. (1979).

The sarcomere lengths (Table 2) of all treatment groups were similar ($P > 0.05$). This indicates that mechanisms other than or in addition to prevention of cold shortening are responsible for the observed improvement in meat tenderness with electrical stimulation. A combination of low pH and high temperature after electrical stimulation could have caused an early release and increased activity of lysosomal enzymes (Moeller et al., 1977).

Cooking loss results are summarized in Table 2. Both of the electrically stimulated groups (at 2 and 16°C) had significantly ($P < 0.05$, $P < 0.01$) lower cooking losses than the nonstimulated group chilled at 2°C; however they had similar ($P > 0.05$) cooking losses to the nonstimulated delay chilled (16°C for 12 hr) group. No differences in cooking losses were observed between electrically stimulated groups (ES+2 and ES+16°C). Our results here seem contradictory to Savel et al. (1978) findings that electrically stimulated meat has significantly higher cooking losses than the unstimulated meat. Unfortunately, the two studies are not directly comparable as different stimulation techniques and conditions were used in the two studies.

W-B shear values (Table 2) and sensory panel evaluations of tenderness (Table 3) agree very closely and indicate that electrical stimulation regardless of postmortem chilling procedures cause a significant ($P < 0.05$) increase in tenderness. Delayed chilling had only a slight ($P > 0.05$) tenderizing effect. These results agree very closely with those reported by Smith et al. (1979).

The panelists were unable to detect any significant ($P > 0.05$) differences in aroma, flavor, juiciness and overall desirability between treatment means.

Several investigators (Bendall et al., 1976; Dutson et al., 1977; Savell et al., 1978; Will et al., 1980) have used the electron microscope technique to detect electrical stimulation-induced changes in meat. Appearance of contraction bands, disruption of sarcomere integrity, swelling of sarcoplasmic reticulum and mitochondria were all reported. Comparison of unstimulated LD muscle, sampled and fixed within 15 min of carcass splitting with the corresponding muscle from stimulated sides, under the same conditions revealed striking differences in their ultrastructure. Whereas the triad and T-systems are closed in the unstimulated sample (Fig. 4b) they are open in the electrically stimulated sample (Fig. 4a). In addition, a narrower I-band and shrunken Z-line were noted in the electrically stimulated sample. At 24 hr postmortem, the combination of electrical stimulation and aging at elevated temperature for 12 hr had produced a pronounced degradation effect on Z-line (Fig. 5a). However, such Z-line degradation was not noted (Fig. 6a) at 24 hr postmortem in the electrically stimulated samples aged at 2°C immediately after the treatment. From this observation it seems reasonable to suggest that the benefit of electrical stimulation can be maintained and the aging period can be reduced if electrically stimulated carcasses are held at elevated temperature (16°C) for 12 hr. At 24 hr postmortem, electron micrographs of unstimulated LD aged at 2°C (Fig. 6b) show no Z-line degradation whereas some Z-line degradation can be seen in the unstimulated LD aged at 16°C for 12 hr postmortem (Fig. 5b).

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