# Effects of low-voltage electrical stimulation and aging on lamb meat quality

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*[1]Département des sciences animales, 2425 rue de l'Agriculture, Université Laval, Québec, Québec, Canada G1V 0A6; [2]Food Research and Development Centre, Agriculture and Agri-Food Canada, 3600 Casavant Blvd West, Saint-Hyacinthe, Quebec, Canada J2S 8E3; [3]Dairy and Swine Research and Development Centre, Agriculture and Agri-Food Canada, 2000 College Street, Sherbrooke, Quebec, Canada J1M 0C8; and [4]Carne Technologies Ltd, 4 Matos Segedin Drive, PO Box 740, Cambridge 3450, New Zealand.*
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Pouliot, E., Gariépy, C., Thériault, M., Avezard, C., Fortin, J., Simmons, N. J. and Castonguay, F. W. 2012. **Effects of low-voltage electrical stimulation and aging on lamb meat quality**. Can. J. Anim. Sci. **92**: 59–66. The aim of this study was to evaluate the effect of electrical stimulation (ES) and aging time on meat quality of heavy lamb as produced in Quebec. Seventy-six Suffolk-sired crossbred male lambs were slaughtered at a target weight of 48–52 kg. Half of them were electrically stimulated (ES vs. control) at 5–10 min postmortem (21 V; 0.25 A; 60 s). Postmortem pH decline and temperature were monitored. After carcass cutting, longissimus dorsi sections were assigned to aging periods of 1, 3 or 8 d. Temperature decline was the same for both treatments ($P = 0.749$). However, ES carcasses always had a lower pH value than controls during the first 24 h ($P < 0.001$) while the ultimate pH was equivalent ($P = 0.803$). Tenderness, as assessed by either Warner-Bratzler shear force (39 carcasses) or sensory evaluation (35 carcasses) was enhanced by both ES ($P < 0.001$) and aging ($P < 0.001$). At each aging time, tenderness was greater for ES meat. In addition, only 3 d of aging were necessary for ES meat to achieve the tenderness level attained by the controls after 8 d. Sarcomeres were longer ($P < 0.001$) in ES meat than in controls while myofibrillar fragmentation index was not affected by ES treatment ($P = 0.743$). Electrical stimulation also had small effects on color parameters ($a^*$, $b^*$ and $L^*$; $P < 0.01$) and flavor ($P = 0.04$). These results provide the first evidence that tenderness of the meat from heavy lambs produced and processed in Quebec could be enhanced by ES, mostly through cold shortening reduction.

**Key words:** Aging, electrical stimulation, lamb, meat, tenderness

Pouliot, E., Gariépy, C., Thériault, M., Avezard, C., Fortin, J., Simmons, N. J. et Castonguay, F. W. 2012. **Effets de la stimulation électrique à bas voltage et de la maturation sur la qualité de la viande d'agneaux**. Can. J. Anim. Sci. **92**: 59–66. L'objectif de cette étude était d'évaluer l'impact de la stimulation électrique (ES) et de la maturation sur la qualité de la viande d'agneau lourd du Québec. Soixante-seize agneaux mâles demi-sang Suffolk ont été abattus au poids cible de 48–52 kg. La moitié des carcasses ont été stimulées électriquement 5–10 min postmortem (21 V; 0,25 A; 60 s). Un suivi de la chute postmortem du pH et de la température a été effectué. Suite à la découpe des carcasses, des sections du longissimus dorsi ont été attribuées à des périodes de maturation de 1, 3 ou 8 j. La chute de la température a été la même pour les carcasses ES et témoins ($P = 0{,}749$). Par contre, la stimulation électrique a engendré un pH inférieur des carcasses au cours des 24 premières heures ($P < 0{,}001$), sans toutefois affecter le pH ultime ($P = 0{,}803$). La stimulation électrique ($P < 0{,}001$) et la maturation ($P < 0{,}001$) ont amélioré la tendreté de la viande déterminée par la force de cisaillement (39 carcasses) et l'analyse sensorielle (35 carcasses). À tous les temps de maturation, la tendreté de la viande ES a été supérieure et seulement 3 j de maturation ont permis à cette viande d'atteindre le même degré de tendreté que la viande témoin maturée 8 j. Les sarcomères des échantillons de viande ES étaient plus longs alors que l'indice de fragmentation myofibrillaire n'était pas affecté par ce traitement ($P = 0{,}743$). La stimulation électrique a eu un léger impact sur les paramètres de couleur ($a^*$, $b^*$ et $L^*$; $P < 0{,}01$) et sur la flaveur ($P = 0{,}04$). Ces résultats apportent une première évidence que la stimulation électrique peut améliorer la tendreté de la viande des agneaux lourds produits au Québec, principalement en réduisant la contraction due au froid.

**Mots clés:** Agneau, maturation, stimulation électrique, tendreté, viande

In Quebec, lamb meat is perceived as a premium meat, consumed mostly on special occasions. In this context, lamb meat quality is a major concern for consumers. With the increasing globalization of market, competition is strong, in terms of price and quantity, but also in terms of quality. To place the lamb industry in a strong

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**Abbreviations:** **ES**, electrical stimulation; **LD**, longissimus dorsi; **MFI**, myofibrillar fragmentation index

competitive position, it is essential to develop practices to optimize lamb meat quality.

Among all production factors, post-slaughter processes have the most important impact on lamb meat quality (Sañudo et al. 1998), with chilling and aging period being critical points. In Quebec, most of the heavy lambs (carcass weight $>20$ kg) are slaughtered in multi-species slaughterhouses designed to chill beef, veal or pork carcasses. As lamb carcasses are smaller and have the greatest surface to volume ratio of these species, they chill faster under the same conditions, making them susceptible to cold shortening of the muscle and hence toughening of the meat (Pearson and Young 1989; Honikel 2004). Ovine muscles are particularly susceptible to this phenomenon due to their proportion of oxidative fibres (Pearson and Young 1989). This susceptibility of lamb muscles to cold shortening combined with the non-homogenous chilling conditions prevailing in Quebec's slaughterhouses processing lamb carcasses are quite unlikely to be optimal for the quality of the meat, especially its tenderness. However, no study on cold shortening has ever been conducted on heavy lambs in the Quebec industry.

Along with carcass cooling, aging is another post-slaughter treatment having a major impact on meat quality. It can affect many aspects of meat quality (color, juiciness and flavor) but tenderization is by far its most beneficial effect (Devine 2004). According to Dransfield et al. (1981) lamb meat would achieve 80% of its final tenderness in 7.7 d. Unfortunately, most of the lamb meat produced in Quebec reaches the market much earlier and sometimes with very little aging, if any (Lévesque and Tremblay 2007).

Electrical stimulation (ES) is a technology that can help with the management of postmortem temperature/pH profile evolution in order to enhance meat tenderness. However, the variability of parameters, such as stimulation protocol, pre-slaughter animal status and chilling procedure, makes the response to the ES highly variable (Hwang et al. 2003; Simmons et al. 2008). Electrical stimulation has been developed in New Zealand for the prevention of meat toughening due to fast chilling (Chrystall and Devine 1985). Electrical stimulation elicits muscle contraction, in this way accelerating the glycolytic process and, reducing the available ATP to fuel contraction during the onset of rigor, thus preventing excessive shortening under cold temperature (Hwang et al. 2003; Devine et al. 2004). Other effects of ES have also been proposed, and mechanisms by which ES affects meat quality are multiple and complex (Hwang et al. 2003; Simmons et al. 2008). In accelerating ATP depletion, ES hasten rigor onset, allowing for an earlier onset of aging juxtaposed to a higher muscle temperature, in this way promoting enzyme activity involved in tenderization (Simmons et al. 2008). Electrical stimulation promotes a faster degradation of different myofibrillar and cytoskeletal proteins (Uytterhaegen et al. 1992; Ho et al. 1996). As both pH and temperature affect enzymes activities, shortening and proteins denaturation altogether, their control through ES and aging management are expected to enhance meat quality.

Therefore, the goal of this study was to evaluate the effect of ES and aging time on the tenderness and overall meat quality improvement of commercial heavy lamb as produced and processed in Quebec.

## MATERIALS AND METHODS

### Animal Management

Lambs used in this experiment were handled in accordance with the guidelines of the Canadian Council on Animal Care (2009).

Seventy-six Suffolk-sired crossbred male were selected at weaning on nine commercial farms and entered the test station (Centre d'expertise en production ovine du Québec, La Pocatière, QC) at $59.5 \pm 0.5$ d of age. During the entire experiment, lambs had ad libitum access to a second-cut hay (mainly timothy grass and brome grass) and a pelleted feed (Puranio 16%, Agribrands Purina; CP: 16%, ADF: 11%, NEg: 2.50 Mcal $kg^{-1}$). They were weighed once a week at fixed day until they reached the targeted fasted body weight of 48–52 kg. The lambs were fasted for approximately 18 h prior to slaughter. They were slaughtered at a commercial slaughterhouse once a week during 8 wk. Each week, lambs reaching the targeted weight were randomly assigned to one of the two post-slaughter treatments: electrical stimulation (ES) or no ES (Control). ES lambs were electrically stimulated within 5–10 min of slaughter. Each ES lamb was hanged by the hind legs and stimulation was applied for 1 min via a neck clip and a rectal probe using a commercial low-voltage system (21 V RMS; 0.25 A; Jarvis, Model ES-4, Middletown, CT). Both ES and control carcasses were pelted, dressed, weighed and transferred to the chilling room ($0.62 \pm 0.80^{\circ}C$) within 20–25 min. During the first 24 h of chilling, temperature and pH decline of the longissimus dorsi (LD) muscle were monitored (Mettler-Toledo LoT406-M6-DXK-S7/25, Mettler Toledo Ingold Inc., Bedford, MA) along the left rack (longissimus thoracis) at 0.75, 3, 6, 12 and 24 h. After overnight chilling, carcasses were graded according to the standard commercial procedure (Agriculture Canada 1992). At 24 h postmortem, carcasses were cut into primal cuts (shoulder, loin, leg, and flank). The loin was separated from the front by a straight cut passing between the 6th and 7th ribs; from the leg by a straight cut passing immediately in front of (anterior to) the pin bone and from the flank by a straight cut parallel to the backbone passing through the 13th rib at the beginning of the costal cartilage. The rack (anterior portion of the entire loin) and the short loin (posterior part), were separated by a straight cut passing behind (posterior to) the 13th rib. Three of the four LD sections thus fabricated (left short loin and right rack and short loin) from each carcass were assigned in balanced design to aging time of 1, 3 or 8 d in order to obtain the same number of

each section for each aging time for both treatments. These LD sections were subsequently used for shear force measurements and sensory evaluation. One-centimeter-thick slices were also collected from these sections and assigned to the same aging time for subsequent determination of myofibrillar fragmentation index (MFI) at the three aging times and sarcomere length at 1 d of aging. All samples were aged under vacuum-packaging at 4°C and were then frozen at −20°C until laboratory analyses. The last section of the LD (left rack) was kept fresh until 48 h postmortem for drip loss, color and ultimate pH measurements.

## Laboratory Analyses

### *Drip Loss, Color and pH*

For drip loss measurements, a slice of 1.5 cm was cut from the fresh LD sections (left rack) at 48 h postmortem. The slice was weighed and suspended for 48 h in a hermetic plastic container maintained at 4°C following the recommendations of Honikel (1987). Drip loss was then determined as the difference between the initial and final weights, expressed in percentage.

The freshly cut surface of the LD section was exposed to air for a 30-min oxygenation period at 4°C and color measurements ($L^*$, $a^*$ and $b^*$) were taken in triplicate using a colorimeter (Chroma Meter CR-300, Minolta Co., Ltd., Osaka, Japan). Ultimate pH (around 48 h postmortem) was also measured in triplicate on the LD section with a probe electrode (Mettler-Toledo LoT406-M6-DXK-S7/25, Mettler Toledo Ingold Inc., Bedford, MA).

### *Cooking Loss and Shear Force*

Shear force measurement was carried on the LD sections (1, 3 and 8 d of aging) of 40 (20 ES and 20 control) carcasses selected at random out of 76 in proportion of the number of individuals slaughtered per week (the remaining LD of 18 ES and 18 control carcasses were used for sensory evaluation). The LD sections were cooked to an internal temperature of 68°C using an autoclave (Autoclave Pilot Rotor 900, Herman Stock Maschinenfabrik Gmbh, Neumunster, Germany) according to the method described by Pouliot et al. (2009). LD sections were weighted before and after cooking to determine cooking loss. Warner-Bratzler shear force (WBSF) measurements were made for each aging time on 1-$cm^2$ meat sticks following the procedure described in Pouliot et al. (2009) using a texturometer (TA-XT2i Texture Analyser, Stable Micro System, Godalming, Surrey, UK).

### *Sarcomere Length*

Sarcomere length on 25 myofibrils having at least 10 sarcomeres was measured from meat slices aged for 1 d, following the procedure described in Gariépy et al. (1992), with a phase contrast microscope (Nikon Eclipse E600, Nikon Canada Instuments inc., Missisauga, ON) equipped with a camera (QImaging Retiga 1300, QImaging, Surrey, BC).

### *Myofibrillar Fragmentation Index*

Myofibrillar fragmentation index was measured after each aging period from a slice obtained from the same LD section as used for the shear force measurement. Duplicate 0.5-g samples of muscle were homogenized on ice in 20 mL of buffer solution ($KH_2PO_4$ 7 mM, $K_2HPO_4$ 18 mM, KCl 0.1 M, EDTA 1 mM et $NaN_3$ 1 mM) during 60 s at 26 000 rpm (Polytron PT 3100, Kinematica, Luzernerstrasse, Lucerne, Switzerland). Myofibrillar fragmentation index was determined using the approach described by Hopkins et al. (2000) based on Culler et al. (1978). Absorption was measured at 540 nm using a spectrophotometer (Varian Cary 50, Varian Instruments, Walnut Creek, CA). Protein concentration was determined using the Bradford method (1976).

### *Sensory Evaluation*

A sensory profile was determined by a panel composed of 12 members who were trained according to the modified SpectrumTM method of descriptive analysis (Meilgaard et al. 2007). Training involved five 1-h sessions of familiarisation with references for specified attributes and intensities as well as three performance tests (repetition with the same four lamb meat samples at each session) to improve the discriminating power, homogeneity and repeatability of evaluation. To determine the sensory profile of the meat from this project, the judges were asked to indicate over six sessions the perceived intensity of flavor, juiciness and firmness characteristics of 108 LD sections (18 LD sections × 2 treatments × 3 aging times) according to Meilgaard et al. (1999). At each session, judges received a sample of each aging time from an ES and control carcasses (six samples). Meat from three animals by treatments was used at each session as one animal was served to four judges. Intensities of flavour, juiciness and firmness were evaluated on a scale of 0 (imperceptible) to 7 (extremely high).

## Statistical Analysis

Two lambs were removed from the analyses because they showed abnormal pH decline and ultimate pH related to the dark, firm and dry (DFD) meat quality defect. The data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc. 2001). Carcasses were randomly assigned to post-slaughter treatment (ES or control) in each of the nine blocks (slaughter days) resulting in a generalized randomized complete block design. For the pH and temperature data, model included slaughter day, treatment (ES or control), postmortem time (0.75, 3, 6, 12 and 24 h) and treatment × time interaction as fixed effects. Postmortem time was considered as repeated measures. For cooking loss, shear force and MFI, slaughter day, treatment (ES or control), aging time (1, 3 or 8 d) and treatment × time interaction

were included in the model as fixed effects. The effect of aging time (1, 3 or 8 d) was treated as a repeated measure since three LD sections of each carcass were allocated to aging time.

For color parameters ($L^*$, $a^*$ and $b^*$) and drip loss assessed at 48 h postmortem, the model included fixed effects of slaughter day and treatment (ES or control).

For the sensory characteristics (firmness, juiciness and flavor), analyses were performed in randomized complete block design with fixed effects of judge × session interaction, treatment (ES or control), aging time and treatment × time interaction included in the model.

Finally, the frequency distribution of shear force around a threshold of 5 kg was analyzed using the LOGISTIC procedure of SAS. Analysis was performed with slaughter day, treatment, aging time and treatment × time interaction as main factors in the model.

Main effects and interactions were considered to be significant at $P<0.05$. When treatment × time interaction was significant, the SLICE option of the LSMEANS statement was used to test the effect of treatment at each time. The Tukey-Kramer adjusted multiple comparisons procedure was used to compare aging time least squares means.

## RESULTS AND DISCUSSION

### Animals

Lambs randomly assigned to post-slaughter treatments had the same growth parameters and carcass traits. ES and control lambs had a slaughter weight of 49.5 ± 1.1 kg. Age at slaughter was 130 ± 17 d and 127 ± 17 d for ES and control lambs, respectively. Hot carcass weight was 22.7 ± 1.0 kg for ES and 22.6 ± 1.1 kg for the control carcasses. Both groups had comparable fat cover measured at the GR site (12th rib, 11 cm from the vertebral column) with 8.4 ± 2.8 mm and 8.4 ± 2.2 mm for ES and control carcasses.

### Temperature and pH decline

The temperature and pH decline (Fig. 1) measured during this project are in accordance with preliminary results obtained in three slaughterhouses in Quebec (data not shown). As expected, temperature decline was the same for ES and control carcasses ($P=0.749$). They reached 10°C within 4 h postmortem and 5°C within 5 h. ES carcasses had a lower pH throughout the first 24 h postmortem ($P<0.001$). The pH difference between control and ES carcasses was about 0.48 pH unit at 45 min postmortem, which is consistent with results from Morton and Newfold (1982), Chrystal and Devine (1985) and Polidori et al. (1999). In control carcasses, mean pH value was around 6.6 when they reached 10°C. Under these conditions of pH and temperature, carcasses are susceptible to cold-shortening since there is significant amount of ATP in the muscle at a temperature where calcium sequestration is reduced (Devine et al. 2004; Honikel 2004). Electrical stimulation, however, depleted ATP allowing carcasses to reach a pH lower than 6.1 at 10°C, reducing the extent of cold shortening. Muscle shortening is known to be minimal when rigor mortis is achieved at 15°C (Locker and Hagyard 1963; Marsh and Leet 1966). More generally, cold-induced toughening would be avoided when pH 6.0 is reached before temperatures fall under 10°C (Devine et al. 2004; Simmons et al. 2008). Given the impact of ultimate pH on all quality parameters, it is important to notice that both type of carcasses attained the same ultimate pH at 48 h postmortem (pH = 5.71; $P=0.803$).

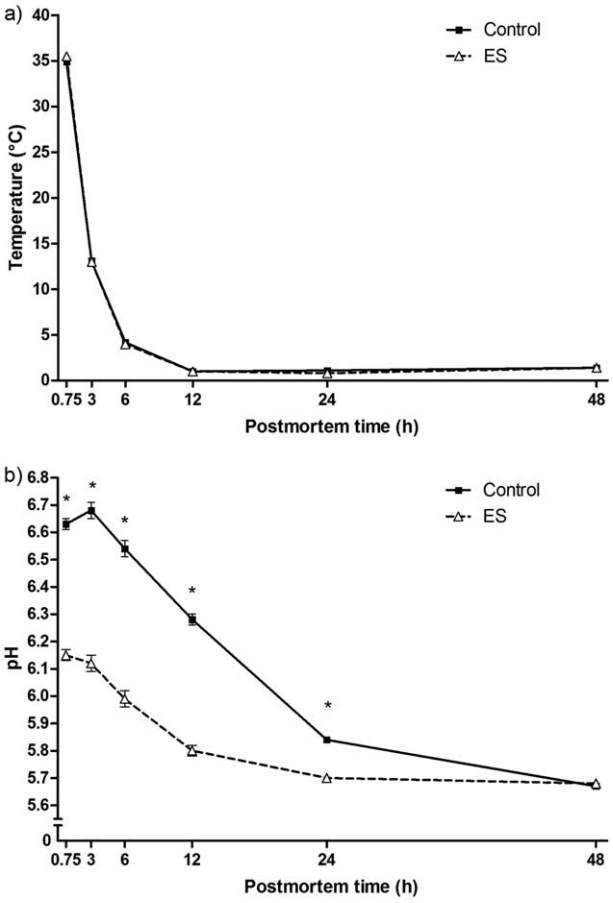


**Fig. 1.** Temperature (a) and pH declines (b) of non-stimulated (Control; $n=37$) and electrically stimulated (ES; $n=37$) heavy lamb carcasses during the postmortem period. *$P<0.05$.

### Color and Drip Loss

Electrical stimulation had an effect on meat color measured 48 h after slaughter (Table 1). The $L^*$ (lightness), $a^*$ (redness) and $b^*$ (yellowness) values were all significantly higher for ES meat, which means that this meat was brighter with a superior tinge of red and yellow compared with the control. Similar effects of ES on LD color were reported following high voltage

**Table 1. Drip loss and color parameters of 48 h postmortem meat from non-stimulated (Control; $n=37$) and electrically stimulated (ES; $n=37$) heavy lamb carcasses**

| | Post-slaughter treatment | | | |
|---|---|---|---|---|
| Variable | Control | ES | SEM | *P* value |
| Color | | | | |
| *a** | 13.17 | 14.42 | 0.28 | 0.001 |
| b* | 6.70 | 7.83 | 0.20 | <0.0001 |
| *L** | 38.24 | 39.47 | 0.32 | 0.004 |
| Drip loss (%) | 1.20 | 1.23 | 0.08 | 0.763 |

(Riley et al. 1981; Kerth et al. 1999) and low voltage treatments (Warner et al. 2005). Some studies, however, did not find any color differences after ES (Toohey et al. 2008). In the present study, these effects on meat color were not due to ultimate pH difference as ES and control carcasses showed comparable values. The faster glycolysis induced by ES might have affected oxygen consumption capacity, allowing for a greater oxygenation of the meat before color measurements (Simmons et al. 2008) leading to the higher $L^*a^*b^*$ color values obtained. This faster glycolysis, however, did not increase drip loss in meat from ES carcasses in comparison with the control (Table 1; $P>0.763$), which indicates that pH decline induced by ES was not faster than desired.

### *Cooking Loss, Tenderness and Sensory Analysis*

Electrical stimulation also had no effect on cooking losses ($P=0.923$) but aging resulted in lower cooking losses (Table 2; $P=0.042$). A similar effect of aging on reduced cooking loss of lamb meat has also been reported by Abdullah and Qudsieh (2009). This effect could be due to a greater water-holding capacity of the meat following aging (Hamm 1986) attributable to the alleviation of the physical constraint following cytoskeletal proteins degradation (Huff-Lonergan and Lonergan 2005). Since drip loss in our study was measured after 48 h, it cannot be ruled out that any subsequent water loss during aging can also potentially influence the cooking loss (Kim et al. 1993).

Electrical stimulation and aging time both enhanced meat tenderness as estimated by WBSF (Table 2; $P<0.0001$). Independently of ES treatment, WBSF decreased with aging time (6.5, 5.2 and 3.5 kg for 1, 3 and 8 d of aging, respectively; $P<0.0001$), an effect that was paralleled by an increase of the MFI over the same period of time (89.5, 103.3 and 112.8 for 1, 3 and 8 d of aging, respectively; $P<0.0001$), indicating the tenderization associated with aging was due to protein degradation. Such effect of aging is well documented (Olson et al. 1976; Culler et al. 1978). Myofibrillar and cytoskeletal proteins are degraded over time following rigor mortis (Taylor et al. 1995) due, in part, to calpain proteases (Koohmaraie and Geesink 2006). An improvement in tenderness higher than 30% was obtain for samples aged for 8 d compared with 3 d. This finding is consistent with results by Dransfield et al. (1981) who reported that 80% of the tenderization occurred in 7.7 d in lamb, while only 50% occurred in 3.3 d.

Regardless of aging time, ES enhanced meat tenderness, as shown by lower WBSF (4.2 vs. 6.0 kg for ES and control carcasses, respectively; $P=0.0001$). This finding is consistent with numerous studies that have demonstrated the beneficial effect of stimulation on tenderness (Hwang et al. 2003; Devine et al. 2004). Contrary to the aging effect being dependent on the myofibrillar protein degradation, the positive effect of ES on tenderness seems to be due to difference in sarcomere length, which were longer in ES meat ($P=0.0002$; Table 2). It is generally accepted that sarcomere length reduction due to muscle shortening induces muscle toughening (Marsh and Leet 1966; Bouton et al. 1973) despite the lack of relationship between the two parameters reported in some studies (Culler et al. 1978). The classic works of Marsh and Leet (1966) and Herring et al. (1967) showed that tenderness decrease rapidly when muscle shortens between 20 and 40%. In our study, the difference in sarcomere length and tenderness between ES and control meat, together with the pH and temperature declines recorded, confirm that control carcasses were subject to the phenomenon of cold shortening. Cooling conditions used were obviously too severe for lamb

**Table 2. Tenderness parameters of meat from non-stimulated (Control; $n=20$) and electrically stimulated (ES; $n=19$) heavy lamb carcasses after three periods of aging (1, 3 and 8 d)**

| | Post-slaughter treatment | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | | ES | | | | *P* value[z] | | |
| Variable | 1 d | 3 d | 8 d | 1 d | 3 d | 8 d | SEM | S | A | S × A |
| Cooking loss (%) | 21.5 | 21.0 | 20.2 | 21.1 | 21.0 | 20.4 | 0.7 | 0.923 | 0.042 | 0.776 |
| Shear force (kg) | 7.69 | 6.00 | 4.25 | 5.39 | 4.36 | 2.81 | 0.38 | 0.0001 | <0.0001 | 0.292 |
| Sarcomere length (μm) | 1.67 | | | 1.75 | | | 0.014 | 0.0002 | | |
| MFI[y] | 89.7 | 104.8 | 112.9 | 89.3 | 101.8 | 112.6 | 4.18 | 0.743 | <0.0001 | 0.774 |

[z]S, stimulation; A, aging.
[y]Myofibrillar fragmentation index.

carcasses and caused a decrease in the tenderness of the final product. The reduction in ATP, reflected in a more rapid pH drop, as a result of ES reduced cold shortening and improved tenderness, as reported in many studies (Chrystall and Hagyard 1976; Davey et al. 1976). In our study however, ES meat displayed shorter sarcomeres than those reported by Warner et al. (2005). Since pH 6.0 was achieved at temperature below 10°C in ES carcasses, occurrence of some muscle shortening cannot be entirely ruled out (Devine et al. 2004; Simmons et al. 2008).

In spite of earlier onset of rigor mortis, as supported by the faster pH decline in ES meat (indicator of energy level; Fig. 1), significant acceleration of aging due to ES as suggested by Geesink et al. (2001) and Simmons et al. (2008) is unlikely in our study. The muscle temperature has already reached 1°C at 10–12 h postmortem for both treatment (Fig. 1), which means temperature offers little measurable or practical benefit in terms of aging. Myofibrillar fragmentation index also supports this assumption since MFI values were similar for both ES and control at each aging time (Table 2). Our results therefore show that, in conditions of rapid chilling, the benefits of ES can be attributed to avoiding the toughening effects of cold shortening, rather than accelerating aging.

In the literature, a 5-kg shear force value corresponds to the tenderness acceptability threshold for lamb meat consumers (Shorthose et al. 1986; Safari et al. 2002). Based on this cut-off, the frequency distribution for the shear force values (Fig. 2) showed most ES meat in our study was acceptable for the consumer (70.9% of WBSF lower than 5 kg). The controls, however, only had one-third of the carcasses within the desired range ($P < 0.0001$). The distribution also indicated aging time improves consumer acceptability of the meat (24.3, 46.0 and 84.2% of meat below 5.0 kg of WBSF at 1, 3 and 8 d; $P < 0.0001$). Moreover, 100% of the ES meat aged for 8 d had WBSF below the 5-kg threshold. Therefore, ES and aging for 8 d could represent a meat tenderness guarantee for Quebec heavy lambs.

Results of the sensory analysis, showed a significant treatment × aging interaction for firmness ($P = 0.023$; Table 3) that was not observed with the carcasses assessed for WBSF. Sensory profiles showed that ES was more tender than control at 3 and 8 d of aging. Similar to WBSF results, firmness score decreased with aging for ES, indicating improved tenderness (Table 3). For the control, a positive effect of aging was perceived only after 8 d. It is noteworthy that mean shear forces for 1 and 3 d aged control and 1 d aged ES (Table 2) were higher than the 5 kg threshold reported for consumer acceptability (Shorthose et al. 1986; Safari et al. 2002), which could have reduced the ability of panelists to discriminate meat according to firmness.

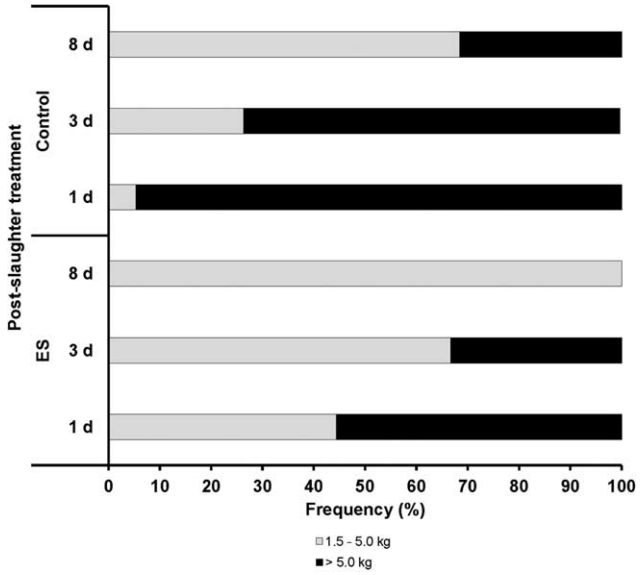


**Fig. 2.** Frequency of meat from non-stimulated (Control; $n = 20$) and electrically stimulated (ES; $n = 19$) heavy lamb carcasses below and over the acceptability threshold of 5 kg for the three periods of aging (1, 3 and 8 d).

It is important to emphasize that ES meat aged for 3 d was as tender as the control aged for 8 d on the basis of shear force, sensory analysis and acceptability. In all cases, ES meat aged for 8 d got the best results.

No significant effect of both ES and aging was perceived by the trained panel on juiciness of the meat

**Table 3. Sensory analysis of meat from non-stimulated (Control; $n = 17$) and electrically stimulated (ES; $n = 18$) heavy lamb carcasses after three periods of aging (1, 3 and 8 d)**

| | Post-slaughter treatment | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | | ES | | | | *P* value[z] | | |
| Variable | 1 d | 3 d | 8 d | 1 d | 3 d | 8 d | SEM | S | A | S × A |
| Firmness | 4.88 | 4.71 | 3.74 | 4.48 | 3.56 | 2.97 | 0.17 | 0.0003 | <0.0001 | 0.023 |
| Juiciness | 3.03 | 2.89 | 2.63 | 2.62 | 2.87 | 2.77 | 0.15 | 0.541 | 0.298 | 0.076 |
| Flavor | 3.86 | 3.77 | 3.92 | 3.55 | 3.63 | 3.59 | 0.11 | 0.017 | 0.822 | 0.633 |

[z]S, stimulation; A, aging.
[y]0 = imperceptible to 7 = extremely high.

(Table 3), which confirms that the effect of aging on cooking losses was minor.

Electrical stimulation also had an effect on meat flavor as perceived by the sensory panel (Table 3). Results indicated that typical ovine flavor was less intense in ES meat than in control. Although small in magnitude, such result can either be regarded as positive or negative depending on consumer preferences for lamb flavor. Electrical stimulation has been reported to improve slightly the flavor desirability scores of beef but not that of lamb (Savell et al. 1977; Riley et al. 1981). Consistent with Boland et al. (2006), who demonstrated that longer chewing increases the release of volatile compounds in gels, it could be hypothesized that tenderness improvement following ES reduced the chewing necessary to degrade the structure of the meat, the liberation of flavor compounds and hence flavor perception.

## CONCLUSIONS AND IMPLICATIONS

The present study shows that lamb meat tenderness is not optimal under the current post-slaughter processes in Quebec. Heavy lamb carcasses are chilled too rapidly, causing toughening of the meat. Most of the lamb carcasses reach the Quebec's markets after 3 d post-mortem, an aging time when meat tenderness is far from that which could be achieved after 8 d as shown in the present study. However, extended maturation requires extra-storage space, which is generally not available in commercial slaughterhouses. Electrical stimulation in combination with 3 d of aging could be used to enhance the tenderness of lamb meat to the level attained after 8 d without ES. Further research could be done to optimize the combined ES and aging treatments to provide a tenderness guarantee for Quebec lamb.

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