Effects of level of current during lamb carcase electrical stimulation on post-mortem muscle changes and meat quality

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ABSTRACT

A study was conducted using 60 lamb carcases to examine the effectiveness of a new type of stimulation system for improving meat quality of lamb carcases. There were 3 treatment groups – control (no current), low current (400 mA) and high current (800 mA). The duration of stimulation was 35 seconds, 20 minutes after death. The stimulation treatments both significantly increased the rate of pH decline and caused an increase in the redness of the *longissimus thoracis et lumborum* muscle. There was no significant reduction in shear force due to stimulation, but ageing for 4 vs 2 days significantly ($P < 0.001$) decreased shear force by on average 12.6 N. There were no significant effects of stimulation on sensory traits, but, as for shear force, ageing significantly ($P < 0.001$) improved tenderness (60 vs 65 on a 0-100 scale). The lack of effect of stimulation may have been due to the high initial tenderness and liking scores of the control samples. These high values occurred in spite of a chilling rate under which cold-induced toughness, and, hence, low tenderness and liking scores, would have been expected.

Keywords: lamb; electrical stimulation; eating quality.

INTRODUCTION

The process of applying electrical currents to carcases with the aim of minimising toughness and improving eating quality has been defined as electrical stimulation, and recently Hwang *et al.* (2003) reviewed the biochemical and physical effects of stimulation on beef and sheep meat tenderness. This review suggested that stimulation units that could respond to each carcase individually and apply the appropriate input of electricity would provide a best practice approach. Traditionally, high voltage stimulation systems used on sheep carcases have applied a fixed voltage averaged across all carcases being stimulated (Devine *et al.,* 2004). Rubbing bars have been used effectively to apply high voltage stimulation to lamb and sheep carcases at the completion of the dressing procedure (Morton *et al.,* 1999; Toohey & Hopkins, 2004), but this process poses concerns for working safety. In Australia a new approach has been developed whereby each carcase is stimulated individually using segmented electrodes to ensure that each segment only contacts one carcase at a time (Devine *et al.,* 2004). This allows computer-controlled electronics to give a precise, but adjustable electrical input to each carcase to match the requirements of a particular carcase type while maintaining the delivery of a pre-determined level of current. In effect a feedback system that detects the level of resistance is used. This approach also reduces the installation costs with respect to occupational health and safety because the power levels and pulse widths used eliminate the need for isolation of the unit, a requirement of high voltage systems.

An experiment was conducted using this new approach to determine an appropriate current level so as to achieve an optimum rate of pH decline. The current levels were selected based on results with a pre-dressing unit Shaw *et al.* (2005) where the current was applied to skin on carcases. This paper reports the results of the experiment and details the impact of the treatments on lamb meat quality.

MATERIALS AND METHODS

Animals and carcases

A total of 60 weaned 5-month-old lambs were processed at a commercial abattoir. All lambs were second cross (sire breed Poll Dorset, dam breed Border Leicester x Merino) from one source and had been grazing clover pasture prior to slaughter. The total time off feed was 43.5 h incorporating 24 h pre-transport, 5.5 h of trucking time and 14 h of lairage.

The 60 lambs were processed in six blocks of 10. Lambs in blocks 1 & 6 received low current stimulation (constant current 400 mA peak, 14 Hz, 1millisecond pulse width, maximum voltage 300 V peak). Lambs in blocks 2 & 5 received no stimulation (controls). Lambs in blocks 3 & 4 received high current stimulation (constant current 800 mA peak, 14 Hz, 1 millisecond pulse width, maximum voltage 300 V peak). The electrical current was applied via rubbing bars to the dressed carcases approximately 20 minutes after stunning and sticking. The total duration of application of the current for each carcase was 35 seconds. At the completion of normal dressing procedures the carcase weight and GR were recorded and the carcases placed in a chiller.

Measurements

Muscle pH and temperature measurements were made after entry into the chiller 55 minutes after death and at approximately hourly intervals thereafter for 6–7 h. These measurements were made at the caudal end of the *longissimus thoracis et lumborum* (LTL) muscle

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over the lumbar/sacral junction (the sheep meat eating quality (SMEQ) site, Anon 2003). Muscle pH was measured using a data-recording pH meter (TPS WP-80) fitted with an intermediate junction electrode (Ionode BNC, Brisbane QLD) and a temperature probe.

The LTL was removed from both sides of the carcase 24 h after slaughter. Muscle colour was measured following exposure of a cut surface of the LTL to air for 30 minutes. A Minolta Chromameter (Model CR-200) set on the L^*, a^*, b^* system (where L^* measures relative lightness, a^* relative redness and b^* relative yellowness) with a D65 illuminant and calibrated with a red tile was set to provide average colour values after three readings per sample.

The first 15 cm of each loin at the cranial end was labelled, vacuum packed and randomly allocated within each carcase to either 2 or 4 days ageing and then tested for Warner-Bratzler (WB) shear force. The 65 g samples for Warner-Bratzler testing were cooked from the fresh state in a waterbath at 70ºC for 30 minutes and then cooled for 30 minutes. Five slices, with a cross sectional area of 1 cm^2, were cut parallel to the muscle fibres and shear force measured using a Lloyd (Lloyd Instruments, Hampshire, UK). Shear force results are reported in the tables as Newtons (N). The remaining portion of each LTL (approx. 25 cm) was vacuum packed, labelled, and air freighted interstate in styro foam boxes for completion of the nominated ageing period (2 or 4 days) and preparation for sensory testing. An ultimate pH measurement was made at 2 days and sarcomere length determined on frozen LTL muscle from samples aged for 2 days using laser light diffraction as reported by Bouton *et al.* (1973).

Sensory assessment

Sensory eating quality assessments were conducted on the loin muscles from 54 lambs with the loins from one lamb per block group excluded from sensory testing due to limitations within the sensory assessment programme. An independent company recruited consumer groups from a broad range of socio-economic backgrounds. These consumers were screened to include only individuals who ate lamb a minimum of once per week. Socio-economic and demographic data were recorded for consumers in the taste panels.

Each sample cut was individually packed and kept frozen (-22°C) until testing. Before testing the samples were microwaved to raise the temperature to approximately -4°C and 5 slices of 15 mm thickness prepared. These slices (steaks) were re-stored at -22°C until thawing at ambient temperature for cooking.

Sample preparation for consumer testing has been outlined by Thompson *et al.* (2005a) with the methodology having been developed and used in the Sheep Meat Eating Quality Programme (SMEQ) undertaken in Australia. Each steak was cut in half after grill cooking (to a medium degree of doneness defined as pink with no red) and prior to testing and each consumer was asked to assess each steak for tenderness, juiciness, liking of flavour and overall liking on a continuous 100 point scale (from 0-100). Each consumer tested steaks from 6 different carcases and ten tastings were conducted for each muscle sample which were averaged to give the final eating quality scores for the muscle. Additionally each consumer was asked to give an overall rating by declaring the sample either; awful, unsatisfactory, good every day (3 star), better than every day (4 star) or premium. These ratings were transposed into a 1-5 numerical scale for overall rating.

Statistical analysis

Carcase traits (weight, GR fat depth) and objective meat quality traits (pH, colour, shear force, sarcomere length) and sample mean sensory scores were analysed using an analysis of variance procedure (Genstat 7.4.1, 2004). Electrical stimulation method and ageing time were fixed effects. The data were blocked for kill group and carcase with stimulation treatment applied to four of the six kill groups with the ageing treatments applied across loins from each carcase. The relationship between overall rating score and overall liking score was derived using linear regression. The rate of pH decline relative to the time of chiller entry for each carcase was described using data from 6 sample points using the following non-linear equation and a non-linear procedure (Genstat 7.1, 2004):

$$pH_t = pH_f + (pH_i - pH_f)\exp^{-kt}$$

where pH_t = pH at time t, pH_f = the ultimate pH, pH_i = the pH at t = 0, k = exponential constant of pH decline (h^{-1}) and t = the time in hours (h).

TABLE 1: Mean meat quality measures according to stimulation treatment.

	Control	Low current	High current	SED
k – rate of pH decline (h^{-1})	-0.13 ^{a}	-0.21 ^{b}	-0.21 ^{b}	0.011
Temperature pH6 (°C)	6.0 ^{a}	16.9 ^{b}	21.5 ^{c}	1.68
Muscle colour				
L^*	34.2	35.3	35.7	0.39
a^*	12.8^a	14.6^b	14.6^b	0.37
b^*	4.1	5.5	5.5	0.45
Ultimate pH	5.52	5.46	5.50	0.04
Sarcomere length (μm)	2.27	2.08	2.14	0.07

Values followed by a different superscript letter in a row are significantly different ($P < 0.05$)

TABLE 2: Mean Warner-Bratzler shear force (N) and cooking loss (%) values according to treatments.

	Nil (control)	Low current	High current	SED	2 day aged	4 day aged	SED
Shear force (Newtons)	33.8	26.5	28.8	2.22	36.0[a]	23.4[b]	1.40
Cooking loss (%)	11.5	13.2	12.4	0.91	11.2[a]	13.6[b]	0.49

Values followed by a different superscript letter in a row are significantly different (P < 0.05)

A similar equation was used to determine the non-linear relationship between temperature and time and the results used to calculate the temperature at pH 6 for each individual carcase.

RESULTS

Carcase characteristics

The mean (± SD) carcase weight and GR fat depth was 20.0 ± 1.5 kg and 15.6 ± 3.4 mm, respectively. These values did not differ significantly between the treatment groups.

Meat quality

Both stimulation treatments significantly (P < 0.05) increased the rate of pH decline compared with the unstimulated carcases (Table 1) and as a consequence the predicted temperature at pH 6.0 was significantly higher (P < 0.05). There was no effect of stimulation on ultimate pH or sarcomere length (P > 0.05). There was a trend (P = 0.06) for higher *L** values for stimulated muscle and these muscles were significantly (P < 0.05) redder (*a** values), but showed no difference in yellowness (*b** values). Stimulation did not significantly decrease (P = 0.096) shear force, but there was a significant reduction in shear force with ageing (P < 0.001), with no significant interaction between stimulation and ageing (Table 2). The only significant (P < 0.001) effect on cooking loss was ageing (Table 2).

For the four sensory traits (tenderness, liking, flavour and juiciness) there was no significant effect of electrical treatment (P > 0.05) (Table 3). The effect of ageing was significant only for tenderness (P < 0.001) with a mean value of 60.2 for 2-day aged LTL and 65.2 for 4-day aged LTL. The interaction terms were only significant (P < 0.05) for juiciness where LTL aged for 4 days had a higher sensory score than LTL aged for 2 days when the carcase was not stimulated. Overall liking score = 1.6 (± 3.88) + 18.9 (± 1.16) (overall rating score) R^2 = 0.71, RSD = 3.8. Based on the relationship derived for this data set between overall liking and the ranking given by consumers, 3 star loin meat has a predicted overall liking score of 58.

DISCUSSION

The electrical stimulation treatments produced meat that was redder (increased *a** values) than that from the control group and there was a tendency also for the meat to be lighter coloured (higher *L** values). It is unlikely that the redder meat colour is of any commercial significance given the fact that *a** values above 19 are needed before consumers respond negatively to lamb meat, but *L** values above 34 are required to avoid consumer resistance (Hopkins, 1996) so any increase in this characteristic is of importance. An increase in *a** values after high voltage stimulation has been reported previously by Hanrahan *et al.* (1998). It has been suggested that one explanation for this effect is the faster fall in pH which causes the muscle proteins from stimulated carcases to approach their isoelectric point much sooner after death, thereby 'opening up' the structure allowing more oxygenation of myoglobin (Lawrie, 1998). Stimulation has also been shown to produce a lighter meat colour in cooked lamb (Hildrum *et al.,* 2000).

Based on results in the SMEQ programme it was recommended that for optimum eating quality the temperature at pH 6 lie within the range of 18-25°C (Thompson *et al.,* 2005b). Of the current levels used in this study the higher level provided the greatest confidence of the carcases reaching pH 6.0 within the optimal temperature range. Temperatures below 12°C may produce cold-induced toughness through pre rigor contracture (Hwang *et al.,* 2003). There are experiments which indicated that cold-induced toughness does occur with lamb (McDonagh *et al.,* 1999; Shaw *et al.,* 2004). McDonagh *et al.* (1999) removed lamb LTL muscles within 30 minute postmortem and stored them at 1°C. Although the temperature at pH 6 was not ascertained, the sarcomere length (1.5 ± 0.08 μm) of these muscles was consistent with cold-shortening. The mean Warner-Bratzler shear values at 1 day (89.8N) and 9 days (62.1N) indicated tough product despite the improvement with ageing. Shaw *et al.* (2004) reported an experiment in which a control (non-stimulated) group achieved a temperature at pH 6 of 7.6°C while stimulated groups achieved temperatures of the order of 25°C at this pH. The mean W-B shear value for the control group of 56.9 N was significantly greater than values of 34.2 N for the stimulated groups after 1 day of ageing. As a W-B value of 49 N is accepted as the tenderness/toughness threshold (Safari *et al.,* 2002) a mean value of 56.9 N as occurred in the control group, indicates an unacceptable degree of toughness. In the current experiment the mean of 40.4 N after 2 days of ageing for non-stimulated meat with only 2 samples (10%) above the 49 N tenderness/toughness threshold indicated that the meat was in general relatively tender despite the fact that the

TABLE 3: Mean sensory assessment scores according to stimulation treatments.

	Control		Low current		High current		SED
Ageing time (d)	2d	4d	2d	4d	2d	4d	
Tenderness	57.2	65.3	62.3	66.2	61.1	64.2	2.76
Liking	62.8	66.2	63.4	65.5	64.9	63.1	1.96
Flavour	64.1	67.7	65.1	65.6	65.9	63.4	1.77
Juiciness	51.1[a]	59.0[b]	53.4[a]	55.5[a]	55.9[a]	53.9[a]	2.37

Values followed by a different superscript letter in a row are significantly different ($P < 0.05$)

temperature at pH 6 was 6.0°C. The sarcomere data indicated that the control muscle was not shortened which provides some explanation for the lower shear force values of this group and the lack of response to stimulation. The absolute values for sarcomere length, irrespective of treatment, were long for post-rigor lamb meat suggesting some stretching (Hopkins *et al.,* 2000), but we have no explanation for these results.

The subjective sensory assessments also confirmed the good eating quality of the control samples with the mean value for overall liking being 62.8 after 2 days of ageing. This approximated the value of 66 suggested as that obtainable for lamb loins under optimal processing conditions (Anon, 2003). Furthermore, there were few scores below 58 which in this data set was the mean score to achieve 'good every day' eating quality. By comparison, the mean overall liking score for the baseline samples in another electrical stimulation experiment was 55.5 (Shaw *et al.,* 2004).

In a study to benchmark a commercial abattoir, lamb carcases processed without a stimulation treatment reached a temperature at pH 6 of less than 10°C (Hopkins *et al.,* 2004). After 3-days ageing the grilled loin samples achieved a mean tenderness score of 62.8 and a mean overall liking score of 63.8. These values lie between those recorded for the 2-day and 4-day aged samples from the control group in the current experiment. Thus, it appears that in two separate experiments, chilling conditions believed likely to produce cold-induced toughness have failed to cause any significant detrimental effect on the eating quality of the aged product.

Although there is evidence that lamb muscles going into rigor at a low temperature (temperature at pH 6 of < 10°C) may not always be tough, caution is needed before concluding that cold-induced toughness is not a practical problem with lamb and therefore there is no requirement for stimulation (Hwang *et al.,* 2003). Geesink *et al.* (2001) reported that the control (non-stimulated) group in a lamb carcase stimulation experiment reached a pH of 6 at a temperature of approximately 1°C. The mean shear force value for this group, after 2 days ageing, was 76 N with the difference between the lowest and highest shear force values being 95 N. Thus, marketing this meat at 2 days post mortem would have meant a large inconsistency in tenderness. The high voltage electrical stimulation group reached a pH of 6 at a temperature of approximately 25°C in the work of Geesink *et al.* (2001). The mean shear force value (62 N) of this group was significantly less than that of the control although it too had a large variation in tenderness.

Despite the finding in the current study that eating quality was not improved by the application of electrical stimulation, the effectiveness of the technology for increasing the rate of pH decline was shown and based on the results the higher current level provided the greatest surety of hitting the ideal temperature/pH window. The ability to meet a pH/temperature window is increasingly becoming a requirement for the processing of lamb in Australia based on the results of the SMEQ program (Young *et al.,* 2005) and for compliance processors are installing stimulation units like the one used in this study. This should provide a level of guarantee about the eating quality of lamb which would not be possible without the use of stimulation.

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