



Improving Tenderness of Forage-Finished Beef Using a Low-Voltage Electrical Stimulator

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What was done (summary)

This study was designed to examine the effectiveness of low-voltage electrical stimulation (ES) in improving meat tenderness of forage-finished beef when used in a small-scale, low-volume slaughter plant. In experiment 1, the effect of ES on postmortem glycolysis was investigated by measuring metabolite concentrations in 10 cattle (5 ES and 5 control). ES accelerated postmortem glycolysis, as demonstrated by the faster depletion of ATP and glycogen and rapid decline of pH in muscles from the ES cattle than those from the control cattle. In experiment 2, loin eye muscle samples from 31 electrically stimulated and 28 non-stimulated cattle were collected to evaluate meat quality traits and to measure cooked meat shear force at day 2, 7, 14, 21, and 28 after slaughter. ES did not affect meat color and firmness. The shear force of the ES group was about 10% lower ($P=0.06$) than that of the control group throughout the 28-day aging period.

Why it was done

Most weaned calves raised in Hawaii are shipped to the U.S. mainland due to high feed costs, loss of large-scale feeding infrastructure, and waste management issues associated with the operation of a feedlot in Hawaii, while grain-finished beef is imported for consumption in Hawaii. This situation raises concerns about the long-term sustainability of the Hawaii beef cattle industry, and much interest has been generated in the production of forage-finished beef in Hawaii. Forage-finished beef in general, as compared to grain-finished beef, has a much lower amount of intramuscular fat, thus forage-finished beef has the potential to meet the demand of today's consumer for leaner, high-value meats.

Forage-finished beef, however, is generally known to be less tender than grain-finished beef. To improve or to reduce the variability of beef tenderness, electrical stimulation of carcasses has been the process most widely used during the normal dressing operation. However, this technique has not been used or documented in Hawaii. Therefore, the objective of this study was to investigate the effect of electrical stimulation (ES) on meat tenderness in forage-finished Hawaii beef. Because most slaughter plants in Hawaii are small, handling fewer than 20 carcasses a day, we used a low-voltage electrical stimulator that can be easily installed without excessive cost. This study examined the efficacy of low-voltage ES in improving beef tenderness in a commercial operation.

Procedures

Electrical stimulation

A low-voltage electrical stimulator (Model BV-80, Jarvis Products Corporation, Middletown, CT) was installed at a local slaughter plant that handles about 20 cattle a day with a line speed of 5 head per hour. The stimulation (21 V, 60 Hz, 0.25 A for 20 sec) was through a nose clamp immediately after bleeding (about 10 min or less after stunning).

Sample collection and preparation

All muscle samples used in this study were obtained during regular operations from a local slaughter plant where the low-voltage electrical stimulator was installed. The slaughter plant processed locally grown forage-finished cattle. The cattle processed in this slaughter plant had grazed on various tropical pastures consisting mainly of kikuyugrass and pangolagrass, with some white clover,

and without concentrate feed supplementation. The animals were of mixed breeds containing various proportions of Angus and/or Hereford. Age of the cattle at the time of slaughter was between 24 and 36 months old.

Experiment 1 was designed to measure the changes in metabolite concentrations during low-voltage electrical stimulation (ES) of carcasses. Ten heifers weighing between 441 and 600 lb were selected and randomly divided into two groups: electrical stimulation (ES) and non-stimulation (NS). About 20 g of longissimus dorsi (LD) muscle samples were taken from the 11th rib at 2, 3, 6, 12, and 24 hr after stunning for the measurement of pH and ATP, glucose-6-phosphate, creatine phosphate, and glycogen concentrations. The samples were immediately frozen in liquid nitrogen and stored in dry ice until analysis.

Experiment 2 was designed to evaluate the effect of low-voltage ES on meat tenderness. LD muscle samples were obtained from 23 steers (12 ES and 11 NS) and 36 heifers (19 ES and 17 NS) from the slaughter facility. Because of the size of the operation and the availability of cattle, the samples were obtained on six separate days (about 10 animals per operation). On each day, the cattle were randomly divided into two groups (ES and NS). Efforts were made to allocate equal distribution of steers and heifers to the NS and ES groups. At 48 hr after slaughter, muscle color, marbling score, firmness, and backfat thickness were measured at the 12th rib following the procedure of Boggs and Merkel (1990). On the same day, whole rib sections between the 7th and 12th rib were removed and transported to the university laboratory for proximate analysis and shear force measurement. Shear force was measured at 2, 7, 14, 21, and 28 days after slaughter.

Muscle metabolites and pH measurements

Frozen samples were pulverized in liquid nitrogen and stored at -70°C until all analyses were completed, a time of less than 2 weeks. Metabolites including glycogen, ATP, and creatine phosphate were determined by the method described by Passonneau and Lowry (1993). The pH was measured in homogenates of 2.5 g muscle in 10 ml of 5 mM iodoacetate/150 mM KCl (adjusted to pH 7.0) according to Bendall (1973).

Proximate analysis

Upon arrival at the laboratory, 0.5- and 2.54-cm-thick slices of LD muscle were cut from the 12th rib side for,

respectively, proximate analysis and day-2 shear force measurement. The remaining sections were packaged in a plastic bag and stored at 4°C while samples were collected for shear force measurement. Samples for proximate analysis were stored at -20°C for later analysis. Moisture and lipid contents were determined according to AOAC methods (1980). Ash content was determined as the residue after combustion at 600°C for six hours. Protein was estimated by the difference between the weight of moisture, ash, and lipid and the total sample weight.

Shear force measurement

Upon reaching to each aging period, a 2.54 cm slice of LD muscle was cut for shear force measurement. The muscle slice was trimmed to less than 2 mm of subcutaneous fat, weighed, packed, and vacuum-sealed in Kapak pouches (Kapak Corporation, Minneapolis, MN). The packages were heated in a water bath at 72°C for one hour, then cooled at room temperature for one hour. The pouches were unwrapped, gently dried, and weighed again. Cooking loss was the difference in weight before and after cooking. For shear force measurement, six core samples (1.3 cm diameter) were taken from the slice after cooking. Each core sample was cut at a speed of 180 mm/min with a Warner-Bratzler blade attached to a TA.XT2 Texture Analyzer (Texture Technologies Group, Scarsdale, New York). The shear force value was the mean of the maximum forces required to shear each set of core samples.

Statistical analyses

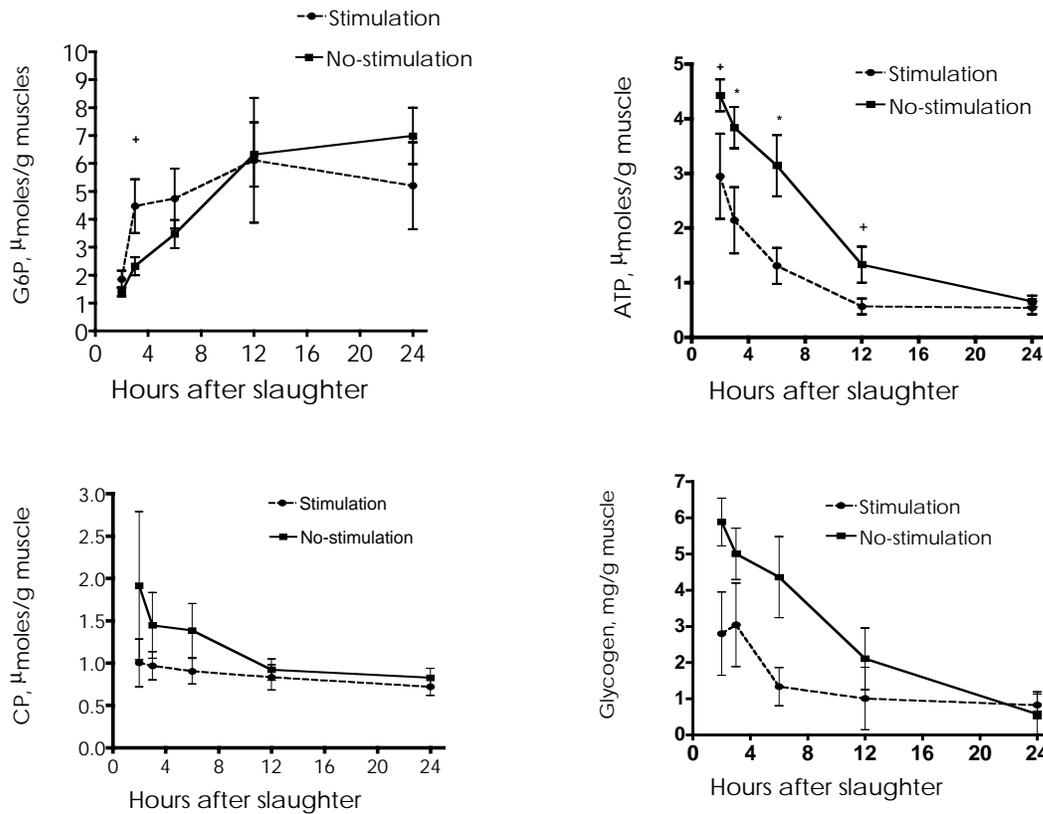
Data were analyzed by the ANOVA procedure using the MINITAB (1989) program. The effect of electrical stimulation on changes in shear force value during the aging period was analyzed by repeated measures analysis of variance using the SAS (1989).

Results and discussion

Experiment 1: Changes in muscle pH and metabolite concentrations by ES

Figures 1 and 2 summarize postmortem changes in the concentrations of ATP, glucose-6-phosphate, creatine phosphate, glycogen, and pH in LD muscles of NS and ES cattle. Electrical stimulation accelerated postmortem glycolysis as demonstrated by the faster depletion of ATP, creatine phosphate, and glycogen from the LD muscle in the ES as compared to the NS group. The creatine phos-

Figure 1. Changes in metabolite concentrations during the 24 hr postmortem period. Data are expressed as mean \pm SEM (n=5); +, $P<0.1$; *, $P<0.05$.



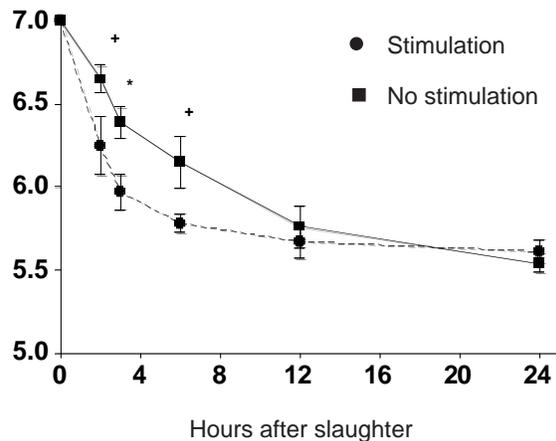
G6P, glucose-6-phosphate; ATP, adenosine tri-phosphate; CP, creatine phosphate.

phate reached its ultimate concentration within 3 hr postmortem in ES muscles but not until 12 hr in NS muscles. ATP and glycogen reached their ultimate concentration within 12 hr postmortem in ES muscles but in over 12 hr in NS muscles. The rise of glucose-6-phosphate was faster in ES muscles than in NS muscles. The decline in pH was accelerated by ES, resulting in a 0.4 unit difference in pH at 2 hr and 3 hr postmortem between the ES and NS groups. The rate of pH decline after low-voltage ES was similar to results reported previously (Aalhus et al. 1994, den Hertog-Meischke et al. 1997).

There have been many investigations as to the relationship between the rate of pH decline and various meat quality traits. According to Smulders et al. (1990), ac-

celerating rigor onset is desirable for meat tenderness, and the most tender meat was produced when the pH value at 3 hr postmortem (pH_3) was between 5.9 and 6.1. Either a slower or more rapid rate of pH decline was detrimental to meat tenderness. Because different methods of ES produce different rates of pH decline (Kastner et al. 1993), the method of ES is likely to be an important consideration in adopting ES technology in slaughter plants. The average pH_3 of ES carcasses in this study was 5.97 with a range between 5.6 and 6.2, while that of the NS group was 6.39 with a range between 6.1 and 6.6. The result, therefore, indicates that the low-voltage ES adopted in this study was appropriate for an optimum acceleration of postmortem glycolysis.

Figure 2. Changes in postmortem muscle pH. Data are expressed as mean \pm SEM (n=5); +, P<0.1; *, P<0.05.



Experiment 2: Effect of ES on lean characteristics, cooking loss, and shear force

The carcass characteristics and proximate analysis of LD muscles of the animals used in this study are summarized in Table 1. When the effect of gender (steer or heifer) on parameters for carcass characteristics, cooking loss, and shear force was included in the model, no effect of gender or gender and ES treatment interaction was observed. Therefore, the gender effect was not separated in the analysis. No significant differences in carcass characteristics, including carcass weight, maturity, backfat thickness, marbling and quality grade, were observed between the two groups.

In general, it is known that ES significantly improves lean color appearance, probably by ensuring more complete postmortem glycolysis within 24 hr (Smith 1985). In addition, ES improved the slight case of dark-cutting beef even though it could not improve the lean color of dark-cutting beef (Smith 1985). A study by Aalhus et al. (1994) also reported that low-voltage ES improved lean color appearance. In the current study, however, no improvement in lean color appearance was observed after ES. The discrepancy may be associated with the timing of lean color evaluation. Most studies evaluated the lean color within 24 hr after slaughter, but in our study we evaluated the lean color at 48 hr after slaughter. This delay probably allowed enough time for completion of

Table 1. Carcass characteristics and proximate analysis of LD muscle.

	No Stimulation	Stimulation	P
Carcass wt (lb)	591.1 \pm 18.7	600.1 \pm 14.3	0.37
Maturity	A	A	
Backfat (in)	0.22 \pm 0.021	0.29 \pm 0.046	0.34
Marbling ^a	3.6 \pm 0.23	3.6 \pm 0.16	0.75
Quality ^b	3.9 \pm 0.35	4.3 \pm 0.25	0.36
Color ^c	4.4 \pm 0.14	4.6 \pm 0.09	0.37
Firmness ^d	4.5 \pm 0.16	4.4 \pm 0.09	0.46
Final muscle pH	5.50 \pm 0.015	5.47 \pm 0.014	0.13
Proximate analysis			
Moisture (%)	73.1 \pm 0.30	72.6 \pm 0.32	0.33
Lipid (%)	2.92 \pm 0.305	3.44 \pm 0.406	0.27
Protein (%)	23.0 \pm 0.12	22.7 \pm 0.15	0.35
Ash	1.04 \pm 0.035	1.19 \pm 0.064	0.12

Data are expressed as mean \pm SEM (n=31 for electrical stimulation and 28 for no stimulation).

^a9 = abundant, 8 = moderately abundant, 7 = slightly abundant, 6 = moderate, 5 = modest, 4 = small, 3 = slight, 2 = trace, 1 = practically devoid

^b8 = prime, 7 = choice⁺, 6 = choice^o, 5 = choice⁻, 4 = select⁺, 3 = select^o, 2 = select⁻, 1 = standard

^c7 = dark, 1 = pale

^d7 = firm, 1 = soft

postmortem glycolysis. In addition, in our study there were no carcasses with dark-cutting or slightly dark cutting beef in either the NS or ES groups, so the effect of ES on this characteristic could not be tested. As with color, there was no significant difference in the 48 hr pH of LD muscle between the ES and NS groups (Fig. 2).

The shear forces required to cut LD muscles and cooking losses are summarized in table 2. Cooking loss was not affected by electrical stimulation. Aalhus et al. (1994) also observed that drip loss and cooking loss were not affected by low-voltage electrical stimulation. The shear force declined rapidly during the first week, then more gradually up to 28 days in both ES and NS muscles. When the effect of ES on shear value was analyzed by repeated measures analysis of variance, electrical stimulation strongly tended ($p=0.06$) to decrease the shear value. The shear value of electrically stimulated LD was about 10% lower than that of non-stimulated LD at 2 days after slaughter, and remained lower throughout the 28 day aging period.

Table 2. Effect of low-voltage electrical stimulation on shear force and cooking loss.

Day	Shear force, kg		Cooking loss, %	
	No Stimulation	Stimulation	No Stimulation	Stimulation
2	8.97 ± .343	8.11* ± .245	22.4 ± .45	22.4 ± .36
7	6.77 ± .263	6.25* ± .223	22.9 ± .75	22.3 ± .54
14	6.35 ± .295	5.83* ± .204	22.3 ± .41	22.4 ± .45
21	5.71 ± .243	5.31* ± .190	22.0 ± .59	22.1 ± .48
28	5.18 ± .215	4.70* ± .116	21.6 ± .35	22.3 ± .39

Data are expressed as mean ± SEM (n=31 for electrical stimulation and 28 for no stimulation).

*When the difference was analyzed by repeated measures analysis of variance, the P value was 0.06.

While many variables are associated with the extent of improvement in tenderness by ES, on the average ES improved tenderness approximately 21% (Smith 1985). Length of time on a high-energy grain diet appears to interact with ES in affecting beef tenderness. Carcasses from cattle fed a high-energy grain diet for a longer period responded with less improvement than carcasses from cattle fed for a shorter period (Salm 1981). In consistent with these findings, the improvement in tenderness by ES was generally greater in forage-finished beef than in grain-finished beef (Smith 1985). In this study, the decrease in shear value by ES was about 10%, and this improvement is far less than the improvement (21–27%) reported by others (Smith et al. 1979, Davis et al. 1981, Schroeder et al. 1982) in forage-finished beef. It had been reported that low-voltage ES is less effective than high-voltage ES in improving meat tenderness (Smith 1985). Aalhus et al. (1994) compared the efficacy of high-voltage and low-voltage ES in improving the tenderness of beef carcasses in two separate experiments. The average tenderness improvement by high-voltage was 20%, while the improvement by low-voltage was 16%. The 16% improvement is higher than our result of 10%, suggesting that in addition to the mode of electrical stimulation, other factors are associated with the extent of improvement in meat tenderness by low-voltage ES. Since low-voltage ES relies on an intact nervous system for the propagation of electrical current,

the timing of application has been noted as the most important factor affecting the effectiveness of ES (Savell 1985). Therefore, to maximize the impact of low-voltage ES, further studies need to examine what variables in operating low-voltage ES influence the effectiveness of electrical stimulation.

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