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Meat Science 60 (2002) 63–68

MEAT SCIENCE

www.elsevier.com/locate/meatsci

Comparison of CO_2 stunning with manual electrical stunning (50 Hz) of pigs on carcass and meat quality

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Received 5 February 2001; received in revised form 9 April 2001; accepted 9 April 2001

Abstract

The effects of carbon dioxide stunning on carcass and pork quality attributes were compared with the effects of manual electrical stunning using either head-only or head-to-brisket electrodes. A total of 30 Large White×Landrace boars (homozygous dominant for the halothane gene) were randomly allocated immediately prior to slaughter to one of three stunning treatments: carbon dioxide (90% CO_2), head only (HO; 1.3 A for 4 s at a frequency of 50 Hz) or head to brisket (HBR; 1.3 A for 4 s at a frequency of 50 Hz) electrical stunning. The pH of the *M. longissimus thoracis* (LT) muscle measured at two sites [between the fifth and sixth thoracic vertebrae (Site 1) and the last thoracic rib (Site 2)] at 40 min post-slaughter was lower ($P<0.001$) in HBR stunned pigs compared with both CO_2 and HO stunned pigs. No differences in ultimate pH of the LT at either measurement site were found due to stunning method. However, a faster ($P<0.05$) relative rate of pH decline was found in the LT at Site 1 from HBR stunned pigs compared with CO_2 stunned pigs. No difference in the relative rate of muscle pH decline ($P>0.05$) between stunning methods was found in the LT muscle at Site 2. Pork from HBR stunned pigs was paler ($P<0.05$) and had a higher ($P<0.001$) percentage drip loss compared with pork from HO and CO_2 stunned pigs. LT muscles from HBR stunned pigs had lower ($P<0.001$) WB shear force values compared with pork from HO stunned pigs (6.57 vs. 8.12 kg, S.E.D. 0.49). Carcass quality was improved by CO_2 stunning, with less ($P<0.05$) ecchymosis-affected pork trimmed from shoulder primals compared with electrically stunned pigs. These results indicate that manual electrical stunning of pigs using HO tongs and CO_2 stunning reduced percentage drip loss, reduced muscle lightness and reduced the rate of muscle pH decline compared with pigs manually electrically stunned using HBR tongs.

Keywords: Stunning pigs; Meat quality

1. Introduction

In many countries, including Australia (Anon, 2001), pigs must be rendered unconscious and insensible to pain prior to exsanguination to be humanely slaughtered. Carbon dioxide and manual electrical stunning are two methods commercially used in Australia to stun pigs for slaughter. Electrical stunning induces unconsciousness by generating an epileptiform seizure, characterised by two distinct phases, a tonic phase and a clonic phase, rendering the animal insensible to pain (Gregory, 1985). The production of an epileptiform seizure is dependent upon the amount of current passing through the brain and possibly the area of the brain through which current flows (Gregory, 1985). The minimum EC requirement for electrical stunning of pigs is a current of 1.25–1.3 A maintained for at least 3 s and the voltage applied to achieve this current must be at least 240 V (Hoenderken, 1978).

Electrical stunning reduces inhibitory influences of the brain on the spinal cord and can lead to kicking during the clonic phase. As a result, pigs may be more difficult to shackle and stick effectively, impairing worker safety (Wotton, 1995) compared with CO_2 stunned pigs that remain relaxed after hoisting. There are several methods used to apply the electrodes used with electrical stunning apparatus including head-only, head-to-back and head-to-brisket application of electrodes (Gilbert, Devine, Hand, & Ellery, 1984). The use of tong-type electrodes are effective for head-only electrical stunning of pigs when applied to each side of the head between the eye and the ear or just below the ears (Grandin, 1980). The head-to-back stunning method was originally developed as an alternative to head-only application of

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0309-1740/01/$ - see front matter
PII: S0309-1740(01)00107-3

stunning electrodes (Wotton, Anil, Whittington, & McKinstry, 1992). Electrical stunning of pigs using head-to-back or head-to-brisket stunning electrodes was also considered the most humane as it induces cardiac fibrillation resulting in immediate cardiac arrest (Wotton et al., 1992). Cardiac fibrillation also eliminates the risk of pigs regaining consciousness prior to exsanguination that can occur due to variation in stun to stick intervals when head only tongs are used. Head-to-back and head-to-brisket stunned pigs generally exhibit less kicking (Wotton et al., 1992), improving worker safety and allowing carcasses to be more easily handled compared with pigs stunned using head-only tongs. It is well recognised that head-to-back stunning of pigs may result in broken vertebrae if voltage applied is too high (Gregory, 1989). However, the effects of manually electrically stunning pigs using head-to-brisket electrodes, that deliver current from both the head and brisket electrodes simultaneously, on the incidence of bone fractures, ecchymosis and meat quality of pigs are less clear.

Ecchymosis is a well recognised defect found in the carcasses of all species of meat animals after electrical stunning (Gregory, 1985). As ecchymosis affected pork may be of lower value than unblemished pork, this problem is of economic significance (van der Wal, 1978). Carbon dioxide stunning is highly effective in terms of decreasing the incidence and extent of ecchymosis, and improving worker safety by reducing kicking (Larsen, 1982) as CO_2 stunned pigs remain motionless for up to 60 s following exposure to CO_2 anaesthesia. Barton-Gade (1993) reported that CO_2 stunning does not reduce the incidence of pale, soft and exudative pork (PSE) but as the immediate pre-slaughter handling of the pigs may be less stressful in a CO_2 stunning system, resultant meat quality may be better than from pigs stunned with electricity.

In this study, carcass and meat quality attributes of pork from pigs electrically stunned using a manual scissor-type head-to-brisket handpiece were compared with pigs stunned using conventional scissor-type head-only tongs and pigs stunned with carbon dioxide. The hypothesis of this experiment was that the incidence of carcass quality defects resulting from head only electrical stunning could be reduced using head-to-brisket electrodes, and therefore provide pig processors with an alternative electrical stunning method to minimise ecchymosis and bone fracture problems whilst improving worker safety.

2. Materials and methods

2.1. Animals and experimental design

Thirty entire male pigs, homozygous dominant for the halothane gene, ranging from 60 to 80 kg liveweight were randomly allocated immediately prior to slaughter to one of three stunning treatments: carbon dioxide (90% CO_2 in air), head-only electrical stunning (HO, 1.3 A for 4 s at a frequency of 50 Hz) or head-to-brisket electrical stunning (HBR, 1.3 A for 4 s at a frequency of 50 Hz). The experiment was conducted using a randomised block design where the order of the three pigs in each block was randomly allocated to stunning treatment.

All pigs were slaughtered in a pilot abattoir, fitted with electrical and CO_2 stunning systems suitable for pigs. The lead-in races from lairage into both stunning systems were similar and adjacent to each other. Two slaughters were conducted over a 4-day period, with 15 pigs (five pigs per treatment) slaughtered on each slaughter day. Pigs were moved with minimal force from the lairage area to the stunning area without the use of electric goads. The carbon dioxide dip lift stunner (Butina APS, Denmark) was set at 90% CO_2 and pigs were exposed to CO_2 for 108 s. Alternatively, pigs were manually electrically stunned in a V-restrainer using a constant current stunning system (Hetech Technologies, Brisbane, Australia) delivering 1.3 A for 4 s, using commercially available Stork® head-only tongs or Stork® head-to-brisket tongs that simultaneously deliver current from both the head and brisket electrodes. The HBR tongs were positioned on the pig with one electrode placed between the ears and the other electrode was placed near the heart between the forelegs on the brisket. The HO tongs were applied to each side of the head between the eye and the ear.

2.2. Slaughter methods

Following stunning, pigs were shackled by the right leg and exsanguinated while hanging. Carcasses were then placed in a dehairer at 62°C for 5 min and hair that remained was removed after exit from the dehairer using a knife and flame. Carcasses were then eviscerated and split before being placed in a chiller set at 4°C for 24 h.

At 24 h post-slaughter, carcasses were dissected into shoulder (cut between the fifth and sixth thoracic vertebrae), middle (cut at the last lumbar vertebrae) and leg primals and weighed. All bones were removed from the shoulder and middle primals and assessed for bone fractures and any muscle tissue affected by ecchymosis was removed, weighed and recorded.

2.3. Meat quality measurements

Muscle samples (~1 g) for glycogen determination were collected from the LT between the 12th and 13th rib using an 8-mm diameter muscle core sampler attached to a cordless drill at 5, 40 min and 24 h post-slaughter. Samples were immediately frozen in liquid nitrogen and transferred 24 h after slaughter to a −80°C

freezer. Glycogen standards and samples were prepared and muscle glycogen measured using the iodine binding assay as described by Dreiling, Brown, Casale, and Kelly (1987). The absorbency measurements were made at 460 nm using a visible light spectrophotometer (Hitachi Model U-2000) after allowing the colour to develop for 15 min subsequent to the addition of the reagent to the standards and samples.

Muscle pH and temperature were determined in two sites in the LT muscle; between the fifth and sixth thoracic vertebrae (Site 1) and at the last thoracic rib (Site 2). Muscle pH and temperature was measured at 40, 90 min, 3, 6 and 24 h post-slaughter using a portable pH meter (Jenco Electronic Ltd., Model 6007) fitted with a polypropylene spear-type gel electrode (Ionode IJ42S, Brisbane QLD) and a temperature probe. Surface lightness of muscle was determined, in triplicate, on a 5 cm thick chop taken from the LT muscle at the P2 site following exposure to air for 10 min using a Minolta Chromameter Model CR-200 using D65 lighting, a 2° standard observer and 8 mm aperture in the measuring head.

Drip loss was measured on LT muscle removed from the carcass at 24 h post-slaughter. At 24 h post-slaughter, muscle from the right LT between the 10th rib and the P2 site was removed of all fat and prepared into 80 ± 2 g samples, in duplicate. Each sample was individually suspended in netting and placed into an air-filled, labelled plastic bag and kept at 4°C for 48 h (Honikel, Kim, Hamm, & Roncales, 1986). Excess moisture was then lightly removed from the muscle surface and samples were re-weighed. Drip loss was calculated and the weight loss was expressed as a percentage of initial weight.

Carcasses were classified to one of three quality classes as defined by Warner, Kauffman, and Greaser (1997), where pHu is defined as ultimate pH at 24 h post-slaughter:

Normal pork	pHu < 6.0, L^* value < 50, drip loss $< 5\%$
Pale, soft and exudative pork (PSE)	L^* value > 50, drip loss $> 5\%$
Dark, firm and dry pork (DFD)	pHu > 6.0, L^* value < 42, drip loss $< 5\%$

Warner–Bratzler shear force (WBSF) of the *M. longissimus lumborum* (LL) muscle was measured at 24 h post-slaughter following cooking as described by Bouton, Harris, and Shorthose (1971). For tenderness assessment, the WB samples were obtained from between the first and fourth lumbar vertebrae and prepared into 100 ± 2 g blocks, in duplicate. After cooking, samples were dried and weighed to determine cooking loss (expressed as a percentage of weight lost due to cooking) and then stored at 4°C for 24 h. From each sample, five 1 cm^2 replicate samples were cut parallel to the orientation of muscle fibres for tenderness assessment. These replicate samples were obtained using a cutting guide comprising of two scalpel blades spaced 1 cm apart and fitted to a handle. All samples were then scored with this guide and then cut using a sharp knife. Tenderness was measured using a Warner–Bratzler shear blade fitted to an Instron Universal Testing Machine Model 4465 with a crosshead speed of 300 mm/min.

2.4. Statistical analyses

A randomised block design was used to allocate pigs into stunning treatment. All data were analysed by analysis of variance using the Genstat 5 program (Payne, Lane, & Genstat 5 Committee, 1987) to determine differences in meat quality attributes due to stunning method.

The rate of muscle pH and temperature decline at both Sites 1 and 2 was examined by fitting pH and temperature data for each individual pig, measured from 40 min to 24 h post-slaughter, to an exponential equation using non-linear regression analysis. Analysis of variance on the k values obtained for each pig was used to determine the influence of stunning method on the k value. The k value can be interpreted as the average relative rate of decay, where relative refers to the difference between the pH/temperature at a particular time to the final pH/temperature at 24 h post-slaughter.

3. Results

3.1. Measurements at slaughter

Muscle pH measured at Site 1 was higher ($P < 0.001$) in CO_2 stunned pigs compared with HO and HBR stunned pigs from 40 min to 6 h post-slaughter (Table 1). Muscle pH at Site 1 in HBR stunned pigs was also lower ($P < 0.001$) compared with HO stunned pigs at 40 min, 3 and 6 h post-slaughter. Muscle pH measured at Site 2 of the LT muscle from 40 min to 6 h post-slaughter was not significantly different between HO and CO_2 stunned pigs, however *M. longissimus thoracis et lumborum* (LTL) from HBR stunned pigs had lower ($P < 0.001$) muscle pH than the other two treatments during this period. Ultimate pH at both sites was not influenced ($P > 0.05$) by stunning method.

When the relative rate of muscle pH decline post-slaughter was examined by fitting data to an exponential curve, LT muscle from pigs in the HBR treatment at Site 1 had a faster relative rate of decline ($P < 0.05$) compared with muscle from CO_2 stunned pigs (0.69 vs. 0.21 pH units/h, S.E.D. 0.147). The relative rate of

Table 1
Effect of head-to-brisket (HBR) electrical stunning, head-only (HO) electrical stunning and carbon dioxide (CO_2) stunning on muscle pH at various times post-slaughter and rate of muscle pH and temperature decline all measured at two sites in the *M. longissimus thoracis et lumborum* (LTL)

	Stunning method				
	HBR	HO	CO_2	S.E.D.	*P*
Muscle pH					
40 min					
Site 1	6.20 a	6.36 b	6.63 c	0.10	<0.001
Site 2	6.23 a	6.57 b	6.62 b	0.08	<0.001
90 min					
Site 1	6.08 a	6.19 a	6.49 b	0.10	<0.001
Site 2	6.19 a	6.51 b	6.40 b	0.07	<0.001
3 h					
Site 1	5.69 a	5.94 b	6.25 c	0.11	<0.001
Site 2	5.98 a	6.44 b	6.34 b	0.11	0.002
6 h					
Site 1	5.66 a	5.77 b	6.01 c	0.07	<0.001
Site 2	5.87 a	6.18 b	6.21 b	0.07	<0.001
24 h					
Site 1	5.60	5.61	5.60	0.03	n.s.
Site 2	5.56	5.61	5.61	0.03	0.076
Relative rate of muscle pH decline to final pH ($hour^{-1}$)*					
Site 1	0.687	0.417	0.205	0.147	<0.05
Site 2	0.313	0.069	−0.058	0.171	n.s.
Relative rate of muscle temperature decline to final temperature ($hour^{-1}$)					
Site 1	0.281	0.350	0.367	0.051	n.s.
Site 2	0.401	0.431	0.450	0.034	n.s.

Means within rows with different letters are significantly different ($P<0.05$).

*Relative to difference between pH/temperature at any given time and final pH/temperature at 24 h post-slaughter.

muscle pH decline from 40 min to 24 h post-slaughter of HO stunned pigs was intermediate between CO_2 and HBR stunned pigs. Stunning method did not influence the relative rate of muscle pH decline at Site 2 nor the relative rate of muscle temperature decline from 40 min to 24 h post-slaughter at both measurement sites.

Muscle glycogen concentrations in the LT muscle between the 12th and 13th thoracic ribs, measured at 5, 40 min and 24 h post-slaughter, were not influenced ($P>0.05$) by stunning treatment (Table 2).

Muscle lightness (L^* value) of the LT muscle from HBR stunned pigs was paler ($P<0.05$) and had a higher percentage drip loss ($P<0.001$) compared with CO_2 and HO stunned pigs. However, the a^* and b^* colour co-ordinate values were not influenced ($P>0.05$) by stunning method. HBR stunned pigs produced pork that recorded lower ($P<0.001$) WBSF (i.e. more tender) compared with HO stunned pigs (6.57 vs. 8.12 kg, S.E.D. 0.49). WBSF of pork from CO_2 stunned pigs was not significantly ($P>0.05$) different to either electrical stunning treatment. No PSE or DFD pork, as defined by Warner et al. (1997), was found in this study.

3.2. Carcass quality

The amount of ecchymosis-affected pork trimmed from shoulder primals was lower from pigs in the CO_2 stunning treatment ($P<0.01$) compared with HO and HBR stunned pigs. No differences were found between HO and HBR stunned pigs in the amount of ecchymosis-affected pork, with an average amount of 101 and 109 g of affected tissue removed, respectively. Overall, a total of 1168 and 1019 g of ecchymosis affected tissue from the shoulder blade was removed from pigs in the HBR and HO treatments, respectively, compared with

Table 2
Effect of head-to-brisket (HBR) electrical stunning, head-only (HO) electrical stunning and carbon dioxide (CO_2) stunning on meat quality attributes and glycogen concentration in the *M. longissimus thoracis et lumborum* (LTL) and the amount of ecchymosis-affected pork trimmed from the shoulder primal

Meat quality attribute	Stunning method				
	HBR	HO	CO_2	S.E.D.	*P*
Meat colour					
L^* value	50.47 a	47.29 b	49.73 b	1.14	<0.05
a^* value	6.02	5.59	5.59	0.24	n.s.
b^* value	3.56	3.20	3.31	0.25	n.s.
Drip loss (%)	4.51 a	2.93 b	2.78 b	0.40	<0.001
WBSF (kg)	6.57 a	8.12 b	7.49 ab	0.49	<0.001
Cooking loss (%)	35.85	34.31	35.16	0.58	<0.05
Muscle glycogen (mg/g)					
5 min	10.3	10.7	11.0	1.8	n.s.
40 min	7.5	7.8	6.9	1.6	n.s.
24 h	2.8	3.9	4.2	1.1	n.s.
Ecchymosis (g)	109 a	101 a	8 b	29.3	<0.01

Means within rows with different letters are significantly different ($P<0.05$).

only 80 g from CO_2 stunned pigs. Ecchymosis-affected pork was trimmed from the loin in only one carcass from the CO_2 stunned treatment, with 47 g of affected tissue removed. No broken bones were found in any shoulder or loin primals in this study.

4. Discussion

The faster rate of muscle pH decline from 40 min to 24 h post-slaughter in the LT muscle at Site 1 in electrically stunned pigs in this study suggests that electrical stunning of pigs, particularly using HBR electrodes, increased the glycolytic rate of muscle post-slaughter compared with pigs stunned with CO_2. This increase in pH decline appears to be similar to that which occurs when pig carcasses are electrically stimulated, as reported by Barton-Gade (1997). In pigs, stimulation of muscles not only increases the immediate rate of pH fall due to energy use during stimulation, but it also increases the rate of pH fall for at least 2 h after the stimulation has occurred (Bendall & Hallund, 1965). A higher level of stimulation in the LT muscle appears to have occurred in this study in HBR stunned pigs where current flow was directed between the brisket and the forehead.

As ultimate pH was not influenced by stunning method, differences in pork quality found in this study may be related to the rate of muscle pH decline during the early post mortem period. HBR stunned pigs had higher percentage drip loss from LT muscles compared with CO_2 stunned pigs, however no differences in percentage drip loss between HO and CO_2 stunned pigs were found. These findings differ from Channon, Payne, and Warner (2000) who reported that HO stunned pigs had higher percentage drip loss from LT muscles compared with CO_2 stunned pigs. Previous studies (Bendall & Wismer-Pedersen, 1962; Fernandez, Culioli, & Gueblez, 1994; Offer, 1991; Sayre, Kiernat, & Briskey, 1964; Woltersdorf & Troeger, 1987) have reported similar findings on the effect of rate of muscle pH decline on percentage drip loss. Additionally, the low incidence of extreme meat quality defects such as PSE and DFD in this study may have been due to minimal handling immediately prior to slaughter (Lewis, Rakes, Brown, & Noland, 1989).

The higher incidence of ecchymosis in electrically stunned pigs observed in this study and previously reported by Aalhus, Gariepy, Murray, Jones, and Tong (1991), Barton-Gade (1997) and Larsen (1982), was considered to result from vascular damage during the tetanic contraction of the muscles which occurs during electrical stunning. Our results indicate that irrespective of the method used to electrically stun pigs in this study, the application of a 1.3 A current for 4 s resulted in a higher incidence of ecchymosis, primarily in the blade musculature of the shoulder. The lower incidence of ecchymosis in CO_2 stunned pigs in this study confirms results of Larsen (1982) that this method of stunning is effective in minimising ecchymosis.

In conclusion, the application of HBR stunning electrodes to pigs in this study increased the rate of muscle pH decline post-slaughter and resulted in paler meat with higher percentage drip loss compared with pigs stunned using CO_2 or electrically using HO electrodes. Pigs stunned with CO_2 had the lowest incidence of ecchymosis in the shoulder and middle primals. The supply of CO_2 stunned pig carcasses to end-users with fewer blemishes can improve both customer satisfaction as well as reduce labour costs associated with trimming of ecchymosis affected meat from affected primals.

Acknowledgements

The authors are appreciative of the funding provided by the Pig Research and Development Corporation to undertake this work. The technical assistance provided by Peter Tardrew, Matthew Kerr, Paul Weston, Bob Nightingale and Richard Biden and statistical advice provided by Kym Butler was appreciated and gratefully acknowledged.

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