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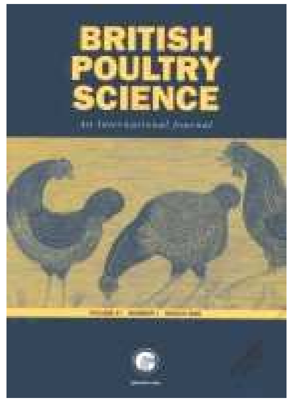

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Broiler carcass quality using head-only electrical stunning in a waterbath.

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Running title: Carcass quality using head-only waterbath stunning

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Abstract 1. The objective of the experiment was to assess the carcass quality of broilers when they were stunned by immersing their heads in a waterbath with an electric current flowing from one side to the other, while a second current passed through the body to the waterbath to prevent involuntary wing flapping.

2. The prevalence of wing, shoulder and breast fillet haemorrhages and broken bones in the pectoral region was not greater than that resulting from the normal stunning practice in the plant (63 mA, 610 Hz pDC).

3. The results imply that carcass damage using this technique will be significantly lower than that which will result from the application higher stunning currents required by the new EU poultry slaughter regulations.

INTRODUCTION

Eight hundred and thirty million broilers are slaughtered each year in the UK, about three quarters of which are killed on a shackle line using electrical waterbath stunning (Anon 2007). In traditional waterbath stunning an electric current passes from the waterbath, through the head, body and legs of the bird, and into the shackle. When suitable electrical parameters are used, this electric current stuns the bird and immobilises the body. However the current also causes broken bones and haemorrhagic damage to a proportion of the carcasses. Since 60% of broilers are sold deboned, this carcass damage is clearly visible to the purchaser and reduces the value of the meat.

The prevalence of carcass damage can be reduced by decreasing the stunning current or increasing its frequency (Veerkamp and de Vries 1983; Gregory and Wilkins 1989; Gregory *et al* 1995). However these changes also decrease the reliability with which the birds are stunned (Raj *et al.* 2006a,b). Selection of the parameters of the stunning current therefore requires that the welfare needs of the broilers are balanced against the commercial needs of the processing plant. Not surprisingly, the relative emphasis given to these aspects is differently by different sections of society.

Research by Raj *et al.* (2004, 2006a, 2006b) indicates that the electric stunning parameters currently used in the industry (typically 600 Hz Pulsed DC current at 80mA rms per bird) do not necessarily result in immediate unconsciousness for all birds. New EC regulations on the protection of animals at the time of killing (EC, 2009) will, from 2013, require the use of minimum stunning currents of 100 mA for frequencies up to 200 Hz, of 150 mA for frequencies of 200-400 Hz and of 200 mA for frequencies of 400-1500 Hz. Barker (2006) indicated that these changes are expected to result in significant increases in carcass damage resulting in a cost to the UK industry over £18m and require an additional 30 million birds to provide sufficient undamaged fillets.

There are indications that head-only electrical stunning results in low levels of carcass damage (Kranen, 1996) however, the difficulty of accurately and rapidly applying the electrodes to the birds' heads means that it is currently not suitable for use in high throughput commercial plants.

Recently, a new concept in head-only stunning was investigated by Lines *et al.* (2011). This method does not require electrodes to be applied directly to the bird's head but rather requires them to be dipped into a waterbath which has an electric current flowing across it from one side of the waterbath to the other. This is fundamentally different from the conventional waterbath where the stunning current runs from the waterbath through the bird's body to the shackles. Since the bird's head does not need to be located and electrodes applied directly, the approach may be suitable for high-speed application in commercial poultry processing plants. In the investigation, electrical stunning parameters which resulted in immediate and prolonged insensibility were identified and a means to prevent the violent involuntary wing flapping which is normally associated with head-only stunning was demonstrated. The practical significance of this development, however, depends on the effect this approach has on carcass quality.

In this paper we report the results of trials designed to examine the carcass damage in birds slaughtered using the head-only waterbath stunning technique. The results are compared against control birds which were killed using a normal waterbath stunning system in a commercial processing plant. By comparing these results against the work of Barker (2006), we make assess the carcass quality obtained by waterbath head-only stunning, those currently achieved in a commercial poultry processing plants, and those which would be obtained using the tunning currents recommended by Raj (2006a,b). The latter are similar to those which will be mandatory in the EU from 2013 (EC 2009).

MATERIALS AND METHODS

Broiler carcass damage measurements were made in two separate but similar studies which took place on separate days during the same week in the same commercial poultry processing plant.

The trials were carried out as a University of Bristol investigation following the approval of the local ethics committee. The stunning methodology that was used had previously been developed and tested under Home Office licence.

Study 1

This trial was carried out at a large commercial poultry slaughter plant almost completely dedicated to slaughtering broiler chickens. Over a period of approximately 5 hours from 08.00, 300 male broilers of 47 days of age and of average live weight 3.49 kg were individually removed from the shackle line post hang-on but before the stun bath. They were transferred to a single shackle suspended on a rope and, when settled, their heads were lowered smoothly into the experimental head-only waterbath stunner. Each bird was subjected to an electrical stun and then immediately transferred to a second shackle on an adjacent fixed frame where an experienced slaughterman employed at the poultry plant cut its neck manually, with the aim of severing both carotid arteries. These birds were then tagged by means of an orange cable tie placed proximal to the hock, removed from the static shackle and returned to the space in the main shackle line from which they had been removed. By this time the shackle was within the bleeding area, beyond the automated neck cutter and just beyond the backup slaughterman.

The treatment birds were stunned by immersing their heads in water in which there was a 50 Hz sinusoidal electric field of 17.5 to 19.0 V/cm rms. The conductivity of the water was between 1.5 mS/cm and 2.5 mS/cm and the stun was applied for 7 ± 1.5 seconds. This stunning field strength was shown by Lines *et al.* (2011) to generate immediate and long lasting unconsciousness within one second of application. To prevent the bird's wings from flapping a 36 ±1.5 mA, 2000 Hz sinusoidal ac current was simultaneously applied through the body of the birds from the shackle to the waterbath. Because both currents are alternating and operating at different frequencies the total current passing through the bird's head was increased by the addition of the second current.

Control birds were drawn from the birds passing normally through the plant at the same time. These were stunned using the normal waterbath stunner which was operating at a frequency of 610 Hz using a 30% duty cycle pulse DC waveform with an rms voltage (ac + dc) of 59.3 V. The average stunning current for these birds, derived by dividing the total current output of the stunner between the 14 birds simultaneously in the waterbath was 63 mA rms (ac + dc) per bird. The birds remained in the waterbath for 9.3 s. This stunning current is substantially below that which will be required by the new EU regulations (EC, 2009)

Following automated plucking, evisceration and chilling, and whilst still on the primary processing shackle line, the carcasses of the treatment birds were scored for external quality. A similar score was also taken from the tenth bird on the shackle line following each treatment bird. This bird became part of the (unmatched) control treatment group.

The inspection focused on four external quality issues known to be susceptible to stunning damage: engorged wing veins, red wing tips, wing haemorrhages and shoulder haemorrhages. The presence of engorged wing veins was noted (0 or 1) while the other three characteristics were scored on a scale from 0 (no damage present) to 3 (severe damage), where scores 0 and 1 represent levels of damage which do not result in carcass downgrading. All external scoring was carried out by the same operator using a subjective comparison against the photographic standards used by Barker (2006). A total of 277 carcasses were scored for each of the treatment and control groups. It was assumed that the 23 treatment carcasses which did not appear at the end of the processing line had been variously rejected by hygiene inspectors, lost from the line or had lost their tags. It was assumed that these carcass were lost at random.

At the end of the primary processing line, treatment and control birds were removed from their shackles and placed in storage bins for overnight storage in a chiller at approximately 4°C. The next morning at 09:00 the bins were removed from the chillers and taken to a processing room where treatment and control birds were manually portioned and a series of further carcass quality measurements were recorded. Carcass portions were presented for scoring, blinded to treatment. Two hundred and seventy treatment birds and 284 control birds were assessed for internal carcass quality.

To assess internal quality, the excised breast muscles were assessed for haemorrhages. The major fillets were assessed as a pair examining both the dorsal and ventral aspect with the skin removed. The minor fillets were also examined as a pair examining the dorsal aspect. The breast fillets were assessed against the photographic standards used by Barker (2006) and scored from 0 (no damage) to 3 where scores 0 and 1 do not result in downgrading. The carcasses were also examined for broken bones by checking the pectoral region for the presence of a broken furculum, scapula or coracoid.

Study 2

During the external inspection of the carcasses from Study 1 it was apparent that treatment carcasses carried a very much higher prevalence of leg damage than control birds. Legs were not included as part of any of the recorded quality assessments because they are not normally vulnerable to damage due to electrical stunning. It appeared that the additional handling received by the treatment birds was causing damage over and above any damage that may have been solely due to the new electrical stunning technique being investigated. The treatment birds received six more handling events than control birds in terms of removal from shackles and re-shackling. Because of the risk that this extra handling might also have a detrimental effect on other aspects of carcass quality, the treatment protocol was modified and the study repeated using a further 300 treatment birds and 300 control birds over the following two days. The handling of treatment birds was modified by taking the birds directly from the delivery module trays rather than removing them from the shackle line. Care was taken to handle the birds gently and to avoid wing flapping. When vigorous wing flapping did occur in a treatment bird it was recorded (by placing the cable tie tag on the alternate leg). The final change to the protocol was to pay more attention to the depth with which the birds were immersed in the stun bath, endeavouring to ensure that birds were not immersed so deeply that their breast muscles were also immersed, as casual observations suggested that this did occur in Study 1.

The study was conducted on 300 45 day-old male broilers of average live weight 3.25 kg, sourced from a different farm from those in Study 1. The treated birds were assessed over a period of five hours starting at approximately 08:00 and were subjected to the head-only waterbath stunning treatment. A total of 284 treatment birds and 284 control birds were scored for external carcass quality and 278 treatment birds and 278 control birds scored for internal carcass quality. Birds that were lost from the study were assumed to be missing at random with respect to the experimental treatment. An assessment of external and internal quality was made as for Study 1.

Statistical Analysis

The software package SPSS v16.0 was used for all analyses. As the weight and origin of the birds used for each of the studies differed and the handling associated with the new stunning treatment was altered between studies, the data from Study 1 and Study 2 were analysed independently. For each study a cross-tabulation of the number of birds in each quality outcome category seperated by treatment and control was produced for each quality measure. Each table was tested for an association between the counts in each quality category and treatment by means of a Chi-square test for the binary outcome measures, or by Kendall's tau-b statistic for those with the ordered, four category outcomes. Exact statistics were calculated in all cases.

Quality measurements with scores of 0 and 1 were considered to have no economic consequence and that scores 2 and 3 would have resulted in downgrading. For these scales the levels 0 and 1 and 2 and 3 were combined into a binary variable signifying no economic consequence (0) or damage of economic significance (1). In this way all of the outcome measures become binary outcomes and were subjected to a secondary analysis using a Chi-square test as described above. As part of this analysis, for all binary outcomes, a lower and upper confidence interval for the percentage difference in quality defects between the two treatments is also presented.

The quality measurements based on records of vigorous wing flapping vigorously in the treatment group were compared with birds in the treatment group that did not flap by means of an exact Mann-Whitney test.

RESULTS

The results for the external quality measures are given in Table 1 as the percentage of birds in each category for the control and treatment groups in Study 1 and Study 2. The results of the internal quality measures are presented in Table 2.

No broken scapulae were found and there were only four birds in which both the furculum and coracoid were broken – one bird occurring in each treatment group and in each control group. Broken bones were therefore scored simply as present or absent (Table 2).

The significance tests for the tests of association between each of the quality measures and treatment are also given in Tables 1 and 2. These indicate there was a difference between control and treatment in the proportion of red wing tips in Study 1, but not Study 2. There was a higher proportion of red wing tips in the treatment group than in the control group (Table 1). There was a smaller proportion of broken bones in the treatment group, but this only reached significance in Study 2 (Table 2). There was a larger number of poor quality scores for the major fillet (dorsal) in the treatment group in both Studies 1 and 2 however for study 2 this was confined to a damage level score of 1 which is not considered to be of commercial significance. There was a higher number of poor quality scores for the minor fillet (dorsal) in the treatment group in Study 1 but not Study 2.

Tests of significance from the exact Chi-square tests for differences in the proportion of commercially significant quality defects between the treatment and control groups, for both Study 1 and for Study 2, are presented in Table 3 with the 95% confidence interval for the percentage difference between the two proportions (treatment percentage minus control percentage). Table 3 indicates that in Study 1 there was a greater proportion of commercially significant damaged minor fillets (dorsal aspect) in the treatment group (P = 0.012, 95%

confidence limits +1.9% to +14.4%) and that in Study 2 the new stunning treatment produced a significantly smaller proportion of carcasses with broken bones ($P = 0.010$, 95% confidence limits -2.1% to -13.7%). No other significant differences were identified between treatment and control groups in either study.

A comparison of the quality measurements from birds within the treatment group which displayed vigorous flapping with those that did not, showed that only the wing haemorrhage scores approached a significant difference ($P = 0.071$), with a greater number of high scores in the flapping group. Of the 284 birds in the treatment group, 40 birds were recorded as displaying vigorous flapping while still alive. The percentage of birds in each group given different wing haemorrhage score are shown in Table 4.

DISCUSSION

The most important results of this set of trials are encapsulated in Table 3 which shows the probable changes in economically significant damage as a result of using the head-only stunning treatment. It shows that the application of the head-only stunning technique under the conditions of Study 1 is likely to have resulted in a small (8% ± 6%) increase in the prevalence of damaged minor breast fillets, but that application of this treatment under the conditions of Study 2 would not result in an increase in damaged breast fillets but the prevalence of broken bones would be decreased by 8% ± 6%.

The change in protocol between Study 1 and Study 2 was focused on reducing the amount of extra handling to which the live birds were subjected and on ensuring that the birds' heads were immersed in the stun bath, whilst keeping their breasts clear of contact with the water.

Both of these changes mean that Study 2 better reflects the conditions of an effectively setup and managed automatic shackle line. Despite these changes the birds in Study 2 were still handled far more than the control birds which remained on the shackle line throughout the stunning and slaughter process. It is entirely reasonable therefore to conclude that the outcome of Study 2 represents the carcass quality that might be achieved if the head-only stunning system was installed and used on a production shackle line, i.e. a small reduction in broken bones and no increase in carcass damage.

The significance of this small reduction in carcass damage in Study 2 and the small increase in Study 1 is that they are delivered using a current which has been shown by EEG analysis to result in immediate and long lasting unconsciousness in a high proportion of the birds (Lines *et al.,* 2010). The control birds, in contrast, were stunned using a current developed to keep carcass damage to an acceptable level. It is less than one third that which will be required under the new EU regulations (EC 2009).

Barker (2006) compared the carcass damage associated with this typical industry stun current to that resulting from application of the higher currents that will be required in 2013. He found that this would at least double the prevalence of haemorrhagic damage in minor breast fillets from 7% to 17% and increase three-fold the prevalence of major breast fillet damage from 4% to 12%.

The cost of this damage to the processor can be estimated by assuming that the breast fillets comprise approximately 10% of the bird weight, that damaged fillet meat has a market value of one third that of undamaged fillets and that undamaged fillets have a market value of £3.5/kg. On this basis the increase in damaged fillets results in a cost to the processor of more than £0.05 for each 3 kg broiler that is to be deboned. Each year in the UK over 370 million birds are sold de-boned so the proposed change in stunning currents would result in a cost of around £18m per year. From an animal welfare point of view, this proposed change could result in a demand for up to 30 million more birds to be slaughtered per year to make up the short fall of undamaged fillets.

The results of both studies therefore represent a very significant improvement in carcass quality compared with that which can be achieved using conventional waterbath stunning for a similar standard of stun.

Despite the positive result of this quality trial, it is important to understand that this head–only stunning technique requires significant further development before it can be installed and tested in a commercial plant. In particular, future research must focus on how the amount of power which must be delivered to the waterbath can be reduced without compromising the quality of the stun achieved and on other practical problems that may be encountered in implementing this approach to stunning in a high speed commercial setting.

Conclusion and animal welfare implications

The most efficient way to improve farm animal welfare is to align the interests of the industry with those of the animal. In traditional electric waterbath stunning the generation of a reliable, immediate and long lasting stun is associated with an increased risk of carcass damage so a compromise between the commercial needs of the industry and the needs of the animals has been adopted. The studies reported in this paper have shown that using head-only waterbath stunning, the quality of the stun applied to the bird need not reduce the quality of the carcass and that this compromise is not needed.

The results show that the carcass damage on birds stunned using a head-only waterbath stunning system is little different from that resulting from normal commercial practice. However the parameters used for the head-only stun have been shown to result in immediate and long lasting unconsciousness (Lines *et al.,* 2010) whereas the effectiveness of the commercially used stun parameters are under question and will not be permitted for general use in the EU after 2013.

Head-only electrical stunning therefore has the potential to meet simultaneously the commercial requirements of the processing industry for high quality meat and the aspirations of society for a high standard of animal welfare at slaughter. Significant further development is however needed to implement this approach in a commercial poultry plant.

ACKNOWLEDGEMENTS

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Table 1. *Carcass quality assessments of birds from the commercial control (C) or experimental head-only stunning treatment (T) for two studies. The significance values of association (P) between the quality measurements and treatment are also given. Where the P value is less than 0.05 the figures are shown in bold.*

Study	Treatment	Engorged Wing Veins			Red Wing Tips, %					Wing Haemorrhage, %					Shoulder Haemorrhage, %				
		n	%	*P*	0	1	2	3	*P*	0	1	2	3	*P*	0	1	2	3	*P*
1	C	277	12	0.45	**78**	**17**	**4.3**	**0.7**	**0.05**	70	20	8.3	2.2	0.54	96	2.2	1.4	0.4	0.11
	T	277	14		**85**	**11**	**3.6**	**1.1**		74	14	6.9	5.4		98	1.4	0.4	0.0	
2	C	284	7.7	0.65	80	15	4.6	0.4	0.66	81	11	6.3	1.4	0.44	99	0.0	0.7	0.1	1.00
	T	284	9.2		79	16	4.6	1.1		79	13	7.4	0.7		99	0.0	0.4	0.4	

Table 2. *The percentage of birds with broken bones and in each internal carcass quality class from control (C) or experimental head-only stunning treatment (T) from two studies. The significance values of association (P) between the quality measurements and treatment are also given. Where the P value is less than 0.01 the figures are shown in bold.*

Study	Treatment	n	Broken bones		Major fillets with haemorrhage, %					Major fillets with haemorrhage, %					Minor fillets with haemorrhage, %				
					Dorsal aspect					Ventral aspect					Dorsal aspect				
			%	*P*	0	1	2	3	*P*	0	1	2	3	*P*	0	1	2	3	*P*
1	C	284	14	0.16	**70**	**22**	**6.3**	**1.8**	**0.006**	50	37	11	2.1	0.34	**21**	**37**	**9.9**	**2.8**	**<0.001**
	T	270	10		**59**	**31**	**9.2**	**1.5**		48	34	14	3.7		**33**	**46**	**17**	**4.0**	
2	C	278	**18**	**0.01**	**83**	**11**	**4.0**	**2.5**	**0.007**	72	22	5.8	0.4	0.62	55	33	9.7	2.5	0.10
	T	278	**10**		**72**	**22**	**3.6**	**1.8**		70	26	3.2	1.4		48	38	12	2.9	

Table 3. *Statistical significance) from the Chi-square tests of association between the quality measures as binary outcomes for Study 1 and Study 2. The 95 per cent upper (UCI) and lower (LCI) confidence intervals for the percentage difference in damage between the treatment and control are also shown (as treatment % – control %). Where the* P *value is less than 0.05, figures are shown in bold.*

Study		Engorged wing vein	Red wing tip	Wing haem	Shoulder haem	Broken bones	Major dorsal	Major ventral	Minor dorsal
	P value	0.446	1.000	0.593	0.216	0.157	0.312	0.124	**0.012**
1	UCI	8.1	3.4	7.2	0.5	1.3	7.6	10.9	**14.4**
	LCI	-3.1	-4.1	-3.5	-3.8	-9.7	-2.3	-1.1	**1.9**
	P value	0.651	0.852	1.000	1.000	**0.010**	0.720	0.574	0.533
2	UCI	6.1	4.6	4.9	1.9	**-2.1**	3.0	2.4	7.9
	LCI	-3.3	-3.1	-4.2	-1.9	**-13.7**	-5.2	-5.4	-3.5

Table 4. *The percentage of birds from the treatment group in Study 2 given each of the Wing Haemorrhage scores broken down by birds which were or were not recorded as flapping vigorously whilst alive.*

Flapping	Wing Haemorrhage Score				
	n	0	1	2	3
No	244	80.3	12.3	7.0	0.4
Yes	40	67.5	20.0	10.0	2.5

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Running title: Broiler carcass quality using head-only waterbath stunning.

Keywords: Animal Welfare, Broiler, Head-only stun, water bath, carcass quality, haemorrhage

Abstract

1. The objective was to assess carcass quality of broilers when they were stunned by immersing their heads in a waterbath with an electric current flowing from one side of it to the other, while a second small current passed through the body to the waterbath to prevent involuntary wing flapping.

2. The prevalence of wing, shoulder and breast fillet haemorrhages and of broken bones in the pectoral region was not greater than that resulting from the normal stunning practice in that plant (63 mA, 610 Hz pDC).

3. These results imply that carcass damage using this technique will be significantly lower than that which will result from the application higher stunning currents required by the new EU slaughter poultry slaughter regulations.

Introduction

Eight hundred and thirty million broilers are slaughtered each year in the UK, about three quarters of which are killed on a shackle line using electrical waterbath stunning (Anon 2007). In traditional waterbath stunning an electric current passes from the waterbath, through the head, body and legs of the bird, and into the shackle. When suitable electrical parameters are used, this electric current stuns the bird and immobilises the body. However the current also causes broken bones and haemorrhagic damage to a proportion of the carcasses. Since 60% of broilers are sold deboned, this carcass damage is clearly visible to the purchaser and reduces the value of the meat.

Carcass damage prevalence can be reduced by reducing the stunning current used or by increasing its frequency (Veerkamp and de Vries 1983, Gregory and Wilkins 1989 and Gregory *et al* 1995) However these changes also decrease the reliability with which the birds are stunned (Raj *et al* 2006a,b). Selection of the stunning current parameters therefore requires that the welfare needs of the broilers are balanced against the commercial needs of the processing plant. Not surprisingly this balance is viewed differently by different sections of society.

Research by Raj *et al* (2004, 2006a, 2006b) indicates that the electric stunning parameters currently used in the industry (typically 600 Hz Pulsed DC current at 80mA rms per bird) do not necessarily result in immediate unconsciousness for all birds. New EC regulations on the protection of animals at the time of killing (EC 2009) will, from 2013, require the use of minimum stunning currents of 100mA for frequencies up to 200 Hz, of 150mA for frequencies of 200-400 Hz and of 200mA for frequencies of 400-1500 Hz. Barker (2006) indicates that these changes are expected to result in significant increases in carcass damage resulting in a cost to the UK industry over £18m and require an additional 30 million birds provide undamaged fillets.

There are indications that head-only electrical stunning results in low levels of carcass damage (Kranen 1996) however, the difficulty of accurately and rapidly applying the electrodes to the birds' heads means that it is currently not suitable for use in high throughput commercial plants.

Recently, a new concept in head-only stunning was investigated by Lines *et al* (2010), which doesn't require electrodes to be applied directly to the birds head but rather requires the birds' heads to be dipped into a waterbath which has an electric current flowing across it from one side of the waterbath to the other. This is fundamentally different from the conventional waterbath where the stunning current runs from the waterbath through the bird's body to the shackles. Since the bird's head does not need to be located and electrodes applied directly, the approach may be suitable for high-speed application in commercial poultry processing plants. In the investigation, electrical stunning parameters which resulted in immediate and prolonged insensibility were identified and a means to prevent the violent involuntary wing flapping which is normally associated with head-only stunning was demonstrated. The practical significance of this development, however, depends on the effect this approach has on carcass quality.

In this paper we report on trials which examine the carcass damage in birds stunned using the head-only waterbath stunning technique. The results are compared against control birds which were killed using a normal waterbath stunning system in a commercial processing plant. By referencing these results against the work of Barker (2006), we make a comparison between the quality results obtained by waterbath head-only stunning, those currently achieved in a commercial poultry processing plants, and those which would be obtained using stunning currents recommended by Raj (2006a,b). These are similar to those which will be mandatory in the EU from 2013 (EC 2009).

Materials and Methods

Broiler carcass damage measurements were made in two separate but similar studies which took place on separate days during the same week in the same commercial poultry processing plant.

These trials were carried out as a University of Bristol investigation following the approval of the ethics committee. The stunning methodology that was used had previously been developed and tested under Home Office licence.

Study 1

This study was carried out at a large commercial poultry slaughter plant almost completely dedicated to slaughtering broiler chickens. Over a period of approximately 5 hours from 08:00, 300 male broilers of 47 days of age and of average live weight 3.49 kg were individually removed from the shackle line post hang-on but before the stun bath. They were transferred to a single shackle suspended on a rope and, when settled, their heads were lowered smoothly into the experimental head-only waterbath stunner. Each bird was subjected to an electrical stun and then immediately transferred to a second shackle on an adjacent fixed frame where an experienced slaughterman employed at the poultry plant cut its neck manually, with the aim of severing both carotid arteries. These birds were then tagged by means of an orange cable tie placed proximal to the hock, removed from the static shackle and returned to the space in the main processing plant shackle line from which they had been removed. By this time this shackle was within the bleeding area, beyond the automated neck cutter and just beyond the backup slaughterman.

The treatment birds were stunned by immersing their heads in water in which there was a 50 Hz sinusoidal electric field of 17.5 to 19 V/cm rms. The conductivity of the water was between 1.5 mS/cm and 2.5 mS/cm and the stun was applied for 7 ± 1.5 seconds. This stunning field strength was shown by Lines *et al* (2010) to generate immediate and long lasting unconsciousness within one second of application. To prevent the bird's wings flapping a 36 ±1.5 mA, 2000 Hz sinusoidal ac current was simultaneously applied through the birds' body from shackle to waterbath. Because both currents are alternating and operating at different frequencies the total current passing through the birds head is increased by the additional of this second current.

Control birds were drawn from the birds passing normally through the plant at the same time. These were stunned using the normal waterbath stunner which was operating at a frequency of 610 Hz using a 30% duty cycle pulse DC waveform with an rms voltage (ac + dc) of 59.3 V. The average stunning current for these birds, derived by dividing the total current output of the stunner between the 14 birds simultaneously in the waterbath was 63mA rms (ac + dc) per bird. The birds remained in the waterbath for 9.3 seconds. This stunning current is substantially below that which will be required by the new EU regulations (EC 2009)

Following automated plucking, evisceration and chilling, and whilst still on the primary processing shackle line, the carcasses of the treatment birds were scored for external quality. A similar score was also taken from the tenth bird on the shackle line following each treatment bird. This bird became part of the (unmatched) control treatment group.

The inspection focused on four external quality issues known to be susceptible to stunning damage: engorged wing veins, red wing tips, wing haemorrhages and shoulder haemorrhages. The presence of engorged wing veins was noted (0 or 1) while the other three characteristics were scored on a scale from 0 (no damage present) to 3 (severe damage), where scores 0 and 1 represent levels of damage which do not result in carcass downgrading. All external scoring was carried out by the same operator using a subjective comparison against photographic standards. These were the same standards as used by Barker (2006). A total of 277 carcasses were scored for each of the treatment and control groups. It was assumed that the 23 treatment carcasses which did not appear at the end of the processing line had been variously rejected by hygiene inspectors lost from the line or had lost their tags. It was assumed that these losses were 'missing completely at random'.

At the end of the primary processing line, treatment and control birds were removed from their shackles and placed in storage bins for overnight storage within a chiller at approximately 4°C. The next morning at 09:00 the bins were removed from the chillers and taken to a processing room where treatment and control birds were manually portioned and a series of further carcass quality measurements were recorded. Carcass portions were presented for scoring, blinded to treatment. Two hundred and seventy treatment birds and 284 control birds were assessed for internal carcass quality.

To assess internal quality, the excised breast muscles were assessed for haemorrhages. The major fillets were assessed as a pair examining both the dorsal and ventral aspect with the skin removed. The minor fillets were also examined as a pair examining the dorsal aspect. The breast fillets were again assessed against the photographic standards used by Barker (2006) and scored from 0 (no damage) to 3 where scores 0 and 1 do not result in downgrading. The carcasses were also examined for broken bones by checking the pectoral region for the presence of a broken furculum, scapula or coracoid.

Study 2

During the external inspection of the carcasses from Study 1 it was apparent that treatment carcasses carried a very much higher prevalence of leg damage than control birds. Legs were not included as part of any of the recorded quality assessments because they are not normally vulnerable to damage due to electrical stunning. It appeared that the additional handling received by the treatment birds was causing damage over and above any damage that may have been solely due to the new electrical stunning technique being investigated. The treatment birds received six more handling events than control birds in terms of removal from shackles and re-shackling. Because of the risk that this extra handling might also have a detrimental effect on other aspects of carcass quality, the treatment protocol was modified and the study repeated using a further 300 treatment birds and 300 control birds over the following two days. The handling of treatment birds was modified by taking the birds directly from the delivery module trays rather than removing them from the shackle line. Care was taken to handle the birds gently and to avoid wing flapping. When vigorous wing flapping did occur in a treatment bird it was recorded (by placing the cable tie tag on the alternate leg). The final change to the protocol was to pay more attention to the depth with which the birds were immersed in the stun bath, endeavouring to ensure that birds were not immersed so deeply that their breast muscles were also immersed. Casual observations had suggested that this was occurring in Study 1.

In this second study which ran over a period of five hours starting at approximately 08:00, 300 45 day-old, male broilers of average live weight 3.25 kg, sourced from a different farm from those in Study 1 were subjected to the head-only waterbath stunning treatment. A total of 284 treatment birds and 284 control birds were scored for external carcass quality and 278 treatment birds and 278 control birds scored for internal carcass quality. Birds that were lost from the study were assumed to be 'missing completely at random'. An assessment of external and internal quality was made as for Study 1.

Statistical Analysis

The software package SPSS v16.0 was used for all analyses. As the weight and origin of the birds used for each of the studies differed and the handling associated with the new stunning treatment was altered between studies, the data from Study 1 and Study 2 were analysed independently. For each study a cross-tabulation of the number of birds in each quality outcome category broken down by treatment and control was produced for each quality measure. Each table was tested for an association between the counts in each quality category and treatment by means of a Chi-square test, for the binary outcome measures, or by Kendall's tau-b statistic for those with the ordered, four category outcomes. Exact statistics were calculated in all cases.

For all the quality measurements which were made on a scale of 0 to 3, levels 0 and 1 are considered to have no economic consequence but levels 2 and 3 will result in downgrading.

For these scales the levels 0 and 1 and 2 and 3 were collapsed to give a binary variable signifying no economic consequence (0) or damage of economic consequence (1). In this way all of the outcome measures become binary outcomes and were then subjected to a secondary analysis using a Chi-square test as described above. As part of this analysis, for all binary outcomes, a lower and upper confidence interval for the percentage difference in quality defects between the two treatments is also presented.

The quality measurements made on birds recorded as flapping vigorously within the treatment group were compared with birds in the treatment group that did not flap by means of an exact Mann-Whitney test.

Results

The results for the external quality measures are given below in Table 1 as the percentage of birds within each score category for the control and treatment groups broken down by Study 1 and Study 2. The results of the internal quality measures are similarly given in Table 2.

No broken scapulae were found and there were only four birds in which both the furculum and coracoid were broken – one bird occurring in each treatment group and in each control group. Broken bones were therefore scored simply as present or absent (Table 2).

The P values from the tests of association between each of the full scale quality measures and treatment are also given in Tables 1 and 2. These indicatet there was a difference between control and treatment in the proportion of Red Wing Tips in Study 1, but not Study 2. There was a greater proportion of Red Wing Tips in the treatment group than in the control group (Table 1). There was a smaller proportion of broken bones in the treatment group, but this only reached significance within Study 2. There was a greater number of poor quality scores for the major fillet (dorsal) in the treatment group within both Studies 1 and 2 however for study 2 this was confined to damage level 1 scores which are not considered to be of commercial significance. There was a greater number of poor quality scores for the minor fillet (dorsal) within the treatment group, but only within Study 1.

Table 3 shows the P values from the exact Chi-square tests for differences in the proportion of commercially significant quality defects between the treatment and control groups, for both Study 1 and for Study 2. Also shown is a 95% confidence interval for the percentage difference between the two proportions (treatment percentage minus control percentage). This table indicates that in Study 1 there was a greater proportion of commercially significant damaged minor fillets (dorsal aspect) in the treatment group (P = 0.012, 95% confidence limits +1.9% to +14.4%) and that in Study 2 the new stunning treatment produced a significantly smaller proportion of carcasses with broken bones (P = 0.010, 95% confidence limits -2.1% to -13.7%). No other significant differences were identified between treatment and control groups within either Study 1 or Study 2.

A comparison of the quality measurements from birds within the treatment group which displayed vigorous flapping with those that did not, showed that only the wing haemorrhage scores approached a significant difference (P = 0.071), with a greater number of high scores in the flapping group. Of the 284 birds in the treatment group 40 birds were recorded as displaying vigorous flapping whilst still alive. The percentage of birds within each group given each wing haemorrhage score are shown in Table 4.

Discussion

The most important results of this set of trials are encapsulated in Table 3 which shows the probable changes in economically significant damage as a result of using the head-only stunning treatment. It shows that the application of this head-only stunning technique under the conditions of Study 1 is likely to have resulted in a small (8% ± 6%) increase in the prevalence of damaged minor breast fillets, but that application of this treatment under the conditions of Study 2 would not result in this increase, but rather only result in a decrease in the prevalence of broken bones by 8% ± 6%.

The change in protocol between Study 1 and Study 2 was focused on reducing the amount of extra handling to which the live birds were subjected and on ensuring that the birds' heads were immersed in the stun bath, whilst keeping their breasts clear of contact with the water. Both of these changes mean that Study 2 better reflects the conditions of an effectively setup and managed automatic shackle line. Despite these changes the birds in Study 2 were still handled far more than the control birds which remained on the shackle line throughout the stunning and slaughter process. It is entirely reasonable therefore to conclude that the outcome of Study 2 represents the carcass quality that might be achieved if this head-only stunning system was installed and used on a production shackle line, ie that a small reduction in broken bones and no increase in other damage is likely to be the quality outcome of such a development.

The significance of this small reduction in carcass damage in Study 2 and the small increase in Study 1 is that they are delivered using a current which has been shown by EEG analysis to result in immediate and long lasting unconsciousness in a high proportion of the birds (Lines *et al* 2010). The control birds, in contrast, were stunned using a current developed to keep carcass damage to an acceptable level. It is less than one third that which will be required under the new EU regulations (EC 2009).

Barker (2006) compared the carcass damage associated with this typical industry stun current to that resulting from application of the higher currents which will be required in 2013. He found this would at least double the prevalence of haemorrhagic damage in minor breast fillets from 7% to 17% and increase three-fold the prevalence of major breast fillet damage from 4% to 12%.

The cost of this damage to the processor can be estimated by assuming that the breast fillets comprise approximately 10% of the bird weight, that damaged fillet meat has a market value of one third that of undamaged fillets and that undamaged fillets have a market value of £3.5/kg. On this basis the increase in damaged fillets results in a cost to the processor of more than £0.05 for each 3kg broiler that is to be deboned. Each year in the UK over 370 million birds are sold de-boned so the proposed change in stunning currents would result in a cost of around £18m per year. From an animal welfare point of view, this proposed change could result in a demand for up to 30 million more birds to be slaughtered per year to make up the short fall of undamaged fillets.

The results of both studies therefore represent a very significant improvement in carcass quality compared with that which can be achieved using conventional waterbath stunning for a similar standard of stun.

Despite the positive result of this quality trial, it is important to understand that this head–only stunning technique requires significant further development before it can be installed and tested in a commercial plant. In particular, future research must focus on how the amount of power which must be delivered to the waterbath can be reduced without compromising the quality of the stun achieved and on other practical problems which may be encountered in implementing this approach to stunning in a high speed commercial setting.

Conclusion and animal welfare implications

The most efficient way to improve farm animal welfare is to align the interests of the industry with those of the animal. In traditional electric waterbath stunning the generation of a reliable, immediate and long lasting stun is associated with an increased risk of carcass damage so a compromise between the commercial needs of the industry and the needs of the animals has been found. The studies reported in this paper have shown that using head-only waterbath stunning, the quality of the stun applied to the bird need not reduce the quality of the carcass so this compromise is not needed.

The results show that the carcass damage on birds stunned using a head-only waterbath stunning system is little different from that resulting from normal current commercial practice. However the parameters used for the head-only stun have been shown to result in immediate and long lasting unconsciousness (Lines *et al* 2010) whereas the effectiveness of the commercially used stun parameters are under question and will not be permitted for general use in the EU after 2013.

Head-only electric stunning therefore has the potential to meet simultaneously the commercial requirements of the processing industry for high quality meat and the aspirations of society for a high standard of animal welfare at slaughter. Significant further development is however needed to implement this approach in a commercial poultry plant.

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Table 1 The percentage of birds from the control (C) or treatment (T) group with engorged wing veins and within each external carcass quality class (0 – 3), broken down by Study. Class 0 indicates no visible damage and class 1 indicates a low level of damage which will not result in downgrading while classes 2 and 3 indicate damage which will result in carcass downgrading (Barker 2006). The *P* values of association between the quality measurements and treatment from the exact Chi-square test (Engorged wing veins) and exact Kendall's tau-b test (remaining measures) are also given. Where the *P* value is less than 0.1 the figures are shown in bold.

			Engorged Wing Veins		% Birds with Red Wing Tips					% Birds with Wing Haemorrhage					% Birds with Shoulder Haemorrhage				
		n	%	*P*	0	1	2	3	*P*	0	1	2	3	*P*	0	1	2	3	*P*
Study 1	C	277	12	0.45	**78**	**17**	**4.3**	**0.7**	**0.05**	70	20	8.3	2.2	0.54	96	2.2	1.4	0.4	0.11
	T	277	14		**85**	**11**	**3.6**	**1.1**		74	14	6.9	5.4		98	1.4	0.4	0.0	
Study 2	C	284	7.7	0.65	80	15	4.6	0.4	0.66	81	11	6.3	1.4	0.44	99	0.0	0.7	0.1	1.00
	T	284	9.2		79	16	4.6	1.1		79	13	7.4	0.7		99	0.0	0.4	0.4	

Table 2 The percentage of birds from the control (C) or treatment (T) group with broken bones and within each internal carcass quality class (0 – 3), broken down by Study. Class 0 indicates no visible damage and class 1 indicates a low level of damage which will not result in downgrading while classes 2 and 3 indicate damage which will result in carcass downgrading (Barker 2006). The *P* values of association between the quality measurements and treatment from the exact Chi-square test (broken bones) and exact Kendall's tau-b test (remaining measures) are also given. Where the P value is less than 0.1 the figures are shown in bold.

			broken bones		% Major Fillets with Haemorrhage (dorsal aspect)					% Major Fillets with Haemorrhage (ventral aspect)					% Minor Fillets with Haemorrhage (dorsal aspect)				
		n	%	*P*	0	1	2	3	*P*	0	1	2	3	*P*	0	1	2	3	*P*
Study 1	C	284	14	0.16	**70**	**22**	**6.3**	**1.8**	**0.006**	50	37	11	2.1	0.34	**21**	**37**	**9.9**	**2.8**	**<.001**
	T	270	10		**59**	**31**	**9.2**	**1.5**		48	34	14	3.7		**33**	**46**	**17**	**4.0**	
Study 2	C	278	**18**	**0.01**	**83**	**11**	**4.0**	**2.5**	**0.007**	72	22	5.8	0.4	0.62	55	33	9.7	2.5	0.10
	T	278	**10**		**72**	**22**	**3.6**	**1.8**		70	26	3.2	1.4		48	38	12	2.9	

Table 3 The *P* values (statistical significance) from the Chi-square tests of association between the quality measures as binary outcomes broken down by Study 1 and Study 2. The 95 per cent upper (UCI) and lower (LCI) confidence intervals for the percentage difference in damage between the treatment and control are also shown (as treatment % – control %). Where the *P* value is less than 0.1, figures are shown in bold.

		Engorged wing vein	Red wing tip	Wing haem	Shoulder haem	Broken bones	Major dorsal	Major ventral	Minor dorsal
	P value	0.446	1.000	0.593	0.216	0.157	0.312	0.124	**0.012**
Study 1	UCI	8.1	3.4	7.2	0.5	1.3	7.6	10.9	**14.4**
	LCI	-3.1	-4.1	-3.5	-3.8	-9.7	-2.3	-1.1	**1.9**
	P value	0.651	0.852	1.000	1.000	**0.010**	0.720	0.574	0.533
Study 2	UCI	6.1	4.6	4.9	1.9	**-2.1**	3.0	2.4	7.9
	LCI	-3.3	-3.1	-4.2	-1.9	**-13.7**	-5.2	-5.4	-3.5

Table 4 The percentage of birds from the treatment group in Study 2 given each of the Wing Haemorrhage scores broken down by birds which were or were not recorded as flapping vigorously whilst alive.

		Wing Haemorrhage Score			
	n	0	1	2	3
Not Flapping	244	80.3	12.3	7.0	0.4
Flapping	40	67.5	20.0	10.0	2.5