RECENT CONCERNS ABOUT STUNNING AND SLAUGHTER

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ABSTRACT

This review summarises information that is relevant to concerns that have recently been expressed about stunning and slaughter. It is known that captive bolt stunning can result in brain material passing to the lungs via the jugular veins. If future studies show that BSE prions pass beyond the lungs to the edible carcass, there will be a move away from captive bolt stunning in large cattle towards electrical stunning. Greater use of electrical stunning in large cattle will increase the importance of blood splash in the beef industry. The theoretical causes of blood splash are reviewed to improve our understanding of this problem. In some situations it can be due to excessive venous pressure causing rupture of a capillary bed some distance from the source of the pressure rise, but it is not known whether this applies to electrical stunning. Gas stunning is replacing electrical stunning for poultry because it can reduce blood spots, which is a similar condition to blood splash. Several gas stunning methods are now being used, but it is not clear which of these is the most humane. Anoxic stunning leads to carcass convulsions and this causes more carcass damage. In fish, recent developments in electrical stunning are showing promise in overcoming problems with carcass damage. It is recommended that rock lobsters should be chilled or frozen before butchery, to ensure a humane death.

Keywords: electrical stunning – gas stunning – captive bolt stunning – BSE – petechial haemorrhage – meat quality – shechita - restraint

INTRODUCTION

There have been two excellent reviews recently on concussion stunning and electrical stunning (Shaw 2002; Schütt-Abraham 1999). The focus in this paper is on recent information not covered in those reviews, and on aspects of stunning and slaughter that are likely to become more important in the next five to ten years. The topics that are discussed include

- BSE and stunning
- Electrical stunning in red meat species
- Electrical stunning in poultry
- Harvesting foetuses
- Fish and crustaceans
- Electrical stunning monitors
- Blood splash and bleeding efficiency
- Religious slaughter
- Gas stunning

In recent years, a large number of abattoirs have changed from working a single shift to two (night and day) shifts. This has allowed better use of infrastructure, and closure of excess slaughter capacity. The effects on the plants that have stayed open include, the need for increased chiller capacity, more precise scheduling of the arrival of stock or greater capacity in the livestock holding area or lairage, and closer attention to rectifying line breakdowns including failure of stunning equipment. Reliability of stunning equipment has become a higher priority, and there is greater willingness to invest in reliable and if necessary sophisticated equipment, especially if there are carcass or meat quality advantages.

BSE and Stunning

There is growing concern that captive bolt guns might be encouraging the distribution of BSE prions from the brain to the edible carcass. In addition, there have been worries about abattoir staff safety when handling CNS material, and particularly from the aerosol of cerebrospinal fluid and spinal cord macerate created during carcass splitting. The history and theory behind these threats is as follows. BSE was first discovered in the UK in November 1986, and by July 1991 about 60,000 cases had been confirmed in Britain. At that time it was well recognised in the medical profession that brain emboli can pass from the brain to the lungs in humans who experience penetrating head injuries (Ogilvy *et al* 1988; Kunz *et al* 1990). For example, brain material had been identified in the pulmonary blood vessels following gunshot wounds in the head (Hatfield & Challa 1980; Miyaishi *et al* 1994), and it had even been known for a bullet to migrate with brain matter to the pulmonary artery (Nehme 1980). The explanation is that when the brain is disrupted, homogenised material can be forced under pressure into the sinuses that drain the brain. Provided the heart is still beating, the particles of brain matter are carried to the heart and then lodge in the capillary bed of the lungs. The lung capillary network has a relatively fine diameter, and so it acts as quite an efficient filter for particulate brain matter that is irrigated out of the brain wound and into the pulmonary circulation (Conhaim *et al* 1998). It would not, however, filter out soluble proteins released from the brain.

In 1991, an attempt was made to introduce a pneumatically powered captive bolt stunner into Europe (Hantover ®). This gun was manufactured in the USA, and it vented some of the spent pneumatic pressure through its bolt into the cranium. This disrupted the brain and produced a relaxed carcass through a pneumatic pithing effect. The gun was disallowed in the UK because it was prone to forcing brain material out of the brain cavity through the bolt hole in the skull and into the operator's face. This was recognised as a hazard for the operator. At about the same time, a hot chining method was developed in the UK which avoided the inhalation of CSF aerosol by abattoir staff (Gregory & Murray 1992). The spinal column was removed intact from the eviscerated carcass using knife work and a pig breastbone opening saw. However, this method was not adopted by the UK meat industry at that time.

The next development came from the USA in 1996, when Garland *et al* (1996) reported that brain emboli could be recovered from 3% of the lungs of cattle stunned with the Hantover stunner. This finding was the death knell for that gun, which is now no longer allowed in the States. Schmidt *et al* (1999a) examined the hearts of cattle stunned with three types of captive bolt gun, for the presence of blood clots. They assumed that clots within the chambers of the heart were a sign of the presence of brain material which acted as nuclei for clot formation. This assumption was never evaluated and is now not widely accepted, and so this piece of work led to some confusion. Shaw & Gregory (2000) subsequently found that modest-sized blood clots occur in the chambers of the heart in over 8% of cartridge-powered captive bolt shot cattle, and in only one of the recovered clots was there material that could be confirmed histologically as originating in the brain. Schmidt *et al* (1999b) developed an assay for detecting filamentous protein of brain origin in beef, but it was not tested sufficiently to demonstrate whether the meat from captive bolt shot cattle presented a risk. Love *et al* (2000), using an ELISA for syntaxin 1B, subsequently found that brain material passes from the head in the blood carried by the jugular vein in captive bolt shot cattle, and the same group confirmed this phenomenon for sheep (Anil *et al* 2002). Daly *et al* (2002) confirmed earlier work by Mackey & Derrick (1979) that marker bacteria that gain access to the brain from captive bolt stunning equipment can end up in muscle. Daly emphasised that if bacteria can be distributed by this route, then so could prion proteins that leak from the brain. The magnitude of the threat of brain material passing through the lungs to the edible carcass in large enough quantities to pose a health risk for consumers has not been established, and it will be difficult to provide any precise answers without having a good estimate of the infective dose required to produce clinical Creutzfeldt-Jakob disease. If the outcome is that captive bolt stunning has to be discontinued, there would be a move towards electrical stunning. Non-penetrating bolt guns cause damage to the brain in some animals, and so they may have a comparable effect to the captive bolt. In which case they would be considered an inappropriate alternative.

When a captive bolt is used, brain tissue and cerebrospinal fluid can leak from the bolt hole in the head for at least 55 min in a suspended carcass (Prendergast *et al* 2003). This leakage contributes to contamination of the surrounding area of the hide as well as the bleeding area plus equipment in the abattoir, and it is thought that it may spread to carcass surfaces especially during the physical movement associated with hide pulling and head removal.

Electrical stunning in red meat species

The potential move away from the captive bolt method towards electrical stunning, raises two questions. How should electrical stunning be applied in large cattle, and does it have any drawbacks ? When using the Jarvis Electrical Stunner that was developed in New Zealand, the recommended minimum current to achieve a satisfactory stun is not less than 1.2 amp, and the current necessary to fibrillate the heart is greater than 1.5 amp (when using nose to brisket electrodes) (Wotton *et al* 2000). One of the shortcomings of electrical stunning in cattle is that it can cause blood splash (ecchymoses or petechial haemorrhage). Anecdotal experience at one plant in New Zealand indicates that blood splash is worse in cattle that carry hormone growth promoter implants, but this has not been authenticated with a controlled study. In earlier work with electrical stunning in cattle there were problems with broken sacrums, but this has now been controlled by using a brisket instead of rump electrode when fibrillating the heart.

About ten years ago, a survey in the UK showed that about 16% of pigs that were electrically stunned manually, were subjected to a repeat application of the current (Anil and McKinstry 1993). Some animals received a second application because the first failed to produce a satisfactory stun. Other pigs received a second current to control carcass kicking and facilitate shackling and hoisting. Some pigs were given a second stun because of an inadvertent delay in sticking. McKinstry & Anil (2004) showed that the effectiveness of a second stun is comparable to that of the first stun, in terms of the duration of epileptiform activity in the EEG, and the time to return of physical brainstem reflexes. The implication is that repeat application of a stunning current is an acceptable procedure when it has to be used, but that situations giving rise to its use should be controlled as far as possible.

Analysis of EEGs using Fast Fourier Transformation has allowed a finer interpretation of EEG traces in electrically stunned animals. This has modified some of our thinking. For example, Velarde *et al* (2002) concluded that in sheep, normal rhythmic breathing activity restarts before epileptiform activity in the EEG has subsided following electrical stunning. Previously, it had been thought that breathing at this stage was abnormal and an involuntary consequence of the physical convulsions. Nevertheless, the resumption of breathing is still regarded as a useful indicator of the imminent return of consciousness.

PSE meat continues to be a problem for pigmeat processors. Besides causing drip, PSE meat is more prone to falling apart when it is sliced thinly. PSE can be limited to zones within a ham and this can make it more difficult to identify suspect carcasses (Franck *et al* 2003). Channon *et al* (2003) confirmed that over-application of electrical stunning increases the risk of PSE meat. This can happen in two ways. Either the current is applied for too long (e.g. 19 *vs* 4 s), or the current is too high (2.0 *vs* 1.3 A). Bertram *et al* (2002) came to the logical conclusion, from using ^{31}P NMR spectroscopy, that the early utilisation of phosphocreatine is an important component determining the link between the physical contractions at the time of stunning and slaughter and post-mortem pH decline.

Electrical stunning in poultry

Blood spots continue to be a problem in the poultry processing sector. However, two developments have helped to reduce their importance; high frequency electrical stunning and gas stunning. In many countries, high frequency electrical stunning has replaced 50 or 60 Hz frequency waterbath stunners. It is well recognised, from work on laboratory animals, that high frequencies (450 Hz and higher) produce less initial spiking and a more even muscle contraction when the current is applied (Rosenblueth and Cannon 1940). During sustained application of the current, muscle tension is lower and the physical contractions are more prone to subsiding, when using high frequencies (Rosenblueth and Luco 1937; 1939). High frequency electrical stunning in poultry usually results in a shorter-lasting stun, and following the current there can be more physical activity (Hillebrand *et al* 1996; Mouchonière *et al* 1999). The greater physical activity is presumably fascicular rather than fibrillary in origin, as it involves whole body responses, but it could also be linked to a lower prevalence of cardiac arrest and hence better oxygenation of nervous as well as muscle tissues. The main commercial advantage with high frequencies is fewer blood spots and other haemorrhages in the carcass, and this could be linked to the reduced muscle tension during stunning. High frequency stunning can also lead to less blood retention in the viscera, and this has benefits in terms of yield of trimmed livers for foie gras production (Turcsán *et al* 2003).

When unrestrained poultry are electrically stunned across the head, they develop severe wing flapping, and because of this, whole-body stunning in a waterbath is preferred. However, a system recently developed at Silsoe Research Institute employs head-only stunning immediately followed by a head to vent current, and this does not provoke any wing flapping. Savenije *et al* (2002a) showed that convulsions involving wing flapping are associated with an impressive acceleration in breast muscle ATP and glycogen depletion, pH decline and lactate accumulation, and the meat has a poorer water holding capacity. Electrical stunning promotes greater depletion of muscle glycogen in Type IIB myofibres (fast twitch glycolytic) in comparison with type IIA fibres (fast twitch oxidative glycolytic) (Iwamoto *et al* 2002).

Electrical waterbath stunners still operate at a constant voltage, even though constant current stunners, that supply current separately to each bird in a waterbath, have been designed, tested and developed (Kettlewell *et al* 1995).

Layer hens are more prone to a cardiac arrest at stunning than broilers, but in practice they are often poorly stunned because of loose-fitting shackles (Schütt-Abraham 1999). When a tissue develops hypoxaemia from a cardiac arrest, the endothelium of the blood vessels becomes leaky and a serous fluid accumulates in the extravascular space. Savenije *et al* (2002b) demonstrated that the accumulation of this fluid in the brain, as measured by the drop in impedance, is very rapid, and that electrical stunning without a cardiac arrest results in a more delayed accumulation of electrolytes in the extravascular space. The significance of these effects in practical terms is not clear, but it is a novel approach to studying the effect of electrical stunning on cell and brain function.

The stunning current recommended for ostriches has been 400 mA or 500 mA when using a 50 Hz AC head only system (Wotton & Sparrey 2002). In practice, currents are often higher than this. For example, the largest ostrich processor applies 400 to 800 mA for 8 to 10 s using 105 V / 50 Hz. Regurgitation during bleeding is a problem at some ostrich processing plants.

Harvesting foetuses

Occasionally there is concern about whether foetuses are conscious when removed from pregnant animals at slaughter. In some countries invasive procedures, such as cardiac puncture for serum collection and recovery of foetal tissues for the Asian health product market, are performed on the foetus as soon as the dam is eviscerated. Under normal circumstances, the foetus is not conscious when it is in the uterus (Mellor & Gregory 2003). In lambs, a relatively high oxygen tension is required to support consciousness, and the p_aO_2 of the foetus is below this level (28 mm Hg pressure) until the lamb starts breathing air. Provided the lamb does not start breathing when it is removed from the amniotic sac, it will not become conscious.

Fish and Crustaceans

The welfare issues associated with killing farmed fish has been reviewed by van de Vis *et al* (2003), and those linked to marine harvesting by Gregory (1998). There has been controversy amongst scientists as to whether fish can feel pain. Some take the view that fish probably cannot feel pain (Rose 2002), whereas others consider that elasmobranches have diminished ability to feel pain but teleost fish probably can (Sneddon *et al* 2002), but it is not clear which types of pain they can feel (Chervova 1997; Gregory 1999). In scientific terms, it is considered that a species can feel pain if it has eight physiological, behavioural and neuroanatomical features (Gregory, 2004). Few species have been examined for all eight criteria, and none of them are fish. In the absence of this information, judgements in the short term will have to be based on individual criteria that seem to be particularly convincing.

Righting behaviour is being used as an indicator of return of consciousness following stunning, and presumably a return of ability to feel pain (Robb *et al* 2002). However, in other species, and in other contexts, this criterion is falling from favour as a good indicator of the interface between consciousness and unconsciousness. It is a cerebellar reflex which can occur in subconscious states, at least in arboreal species such as the Australian brushtail possum (Littin 2004). The difference in value attached to this criterion needs to be reconciled.

The minimum current necessary to stun eels is 600 mA (Lambooij *et al* 2002a). This recommendation was based on the induction of an epileptiform EEG in the brain, and it applies to head only stunning, which is not a feasible method in large scale eel farms (Robb *et al* 2002). Lambooij *et al* (2002b) tested the more practical alternative of passing current through a tank of eels in water, and concluded that a satisfactory amp/dm^2 was 0.64. However the eels were prone to recovering before they died, and so it was recommended that the current should be followed by a second lower but longer-lasting current plus partial deoxygenation of the water using nitrogen. This additional procedure ensured that there was no recovery. When eels were killed in this way, their meat was less prone to oxidative rancidity, and was firmer and redder in comparison with the traditional method of placing the live eels in a bin with crushed salt (Morzel & van de Vis 2003). An in-line semi-automated rotary electrical stunning unit has been developed by Silsoe Research Institute (Lines *et al* 2003).

Concussion seems to be the stunning method that has the least effect on post-mortem muscle metabolism in fish (Ruff *et al* 2002). Linked to this, rigor sets in later, and there is reduced risk of meat gaping. Electrical stunning suffers from the disadvantage that it can result in blood spots (van de Vis *et al* 2003), but in trout this defect can be controlled by using a high frequency (1000 Hz) current (Lines *et al* 2003).

Iso-eugenol (Aqui-S) continues to be used for pre-slaughter sedation of salmon in the aquaculture industry in New Zealand, in spite of concerns by Japanese consumers about flavour residues. Aqui-S and clove oil have been trialled successfully in crabs (*Pseudocarcinus gigas*) destined for human consumption.

The methods used in some Asian restaurants for killing rock lobsters have been receiving media attention. A range of methods are used, including those shown in Figure 1. They are 'drowning' in freshwater, boiling, head spiking, chest spiking, splitting, tailing, and they may or may not be preceded by chilling or freezing. Most lobsters are split longitudinally and the carapace is used in presenting the meat, and they may or may not have been chilled, given a head or chest spike, or tailed before splitting. It is recommended that the lobsters are chilled to less than 4 °C before they are killed (Lowe and Gregory 1999).

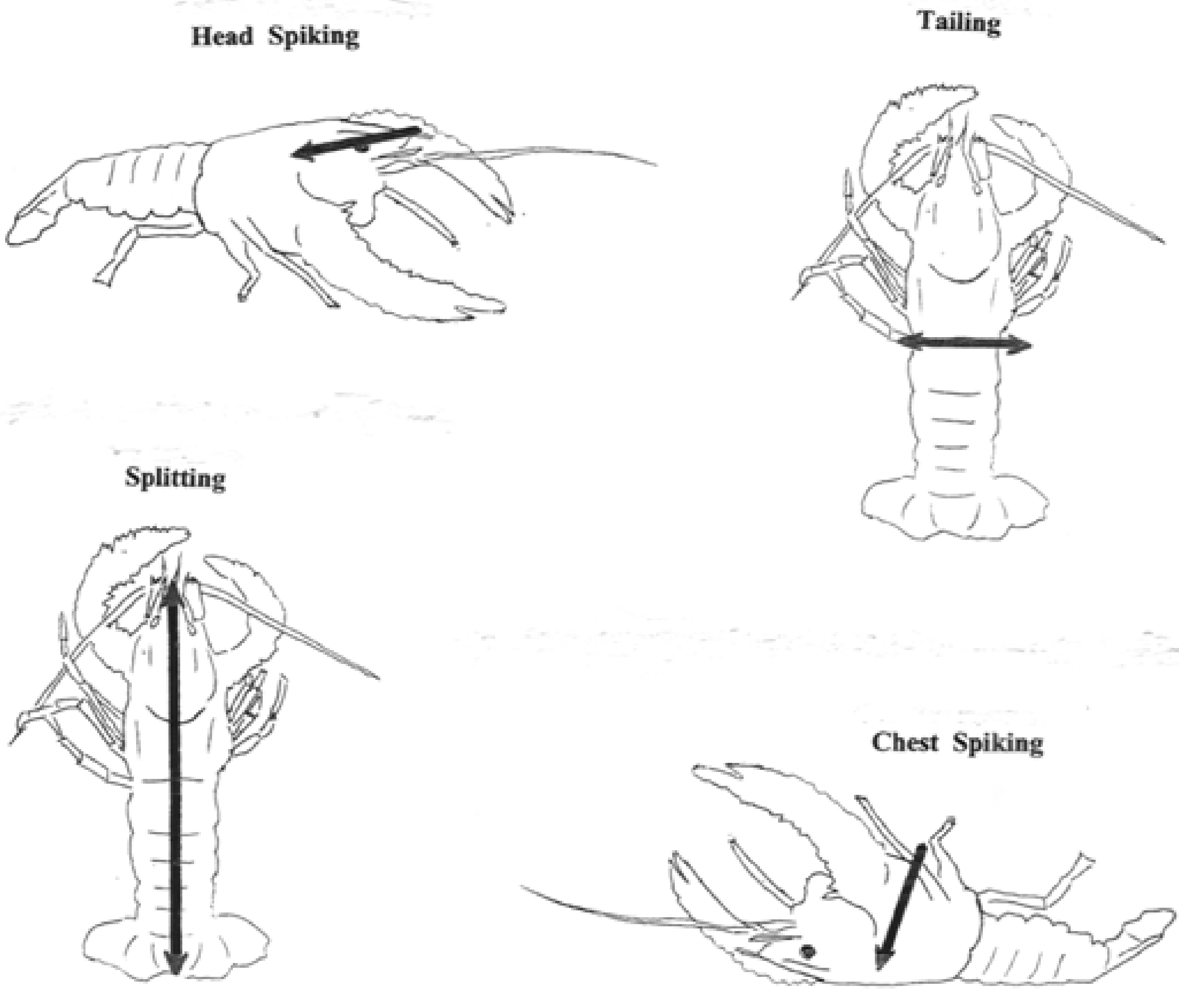

Figure 1. Approaches used in restaurants for killing rock lobsters with a knife or cleaver.

Electrical stunning monitors

Electrical stunning monitoring systems have become more sophisticated in recent years (Berry *et al* 2002; Gregory 2001). The advantage of stunning monitors compared to visual inspection of animals, or looking at the needle of an ammeter connected to the circuit, is that they can identify problems such as pre-stun shocks, interruptions in current flow at the start of stunning, and slow ramping up of the current as it is delivered. A system developed by Silsoe Research Institute for poultry waterbath stunners uses a data logger which is fitted between the shackle and an individual bird. It records rms current, peak current, voltage and duration of current flow for that bird, and the AC and DC measurements are used for determining true rms current.

Blood splash and bleeding efficiency

Four theories have been put forward to explain the cause of the blood capillary rupture that leads to blood splash, but none of these have been proven. Firstly, it could be due to counteracting muscle contractions during stunning causing localised tearing of the capillary bed (Gregory 1998). However, haemorrhages can be induced electrically in tissues such as the brain, which does not possess any skeletal muscle (Hassin 1933). If this applies more broadly, it is unlikely that localised striated muscle contraction is the only cause of vessel rupture. Secondly, Shaw *et al* (1971) suggested that one of the contributing factors may be arteriolar dilatation. This was based on the finding that, in rats, propranolol reduced and phentolamine increased the extent of blood splash. The effects of these drugs would not necessarily be limited to the arterial side of the circulation, as venous dilatation could also play a role (Vanhoutte *et al* 1981). Presumably, it is engorgement of the capillary bed which encourages rupture of vessels when placed under pressure. Thirdly, the blood vessels may be unduly fragile. Histological examination of blood splash in meat has shown that the vessels that burst are on the venous side of the capillary bed, which has less elastic walls than the arterial side, and so are weaker and more prone to damage. Blood splash is common in animals that have died from anticoagulant poisoning and these animals have raised capillary fragility (Littin 2004; Fulton & Berman 1964). It has been noted that lambs in a flock that had a high prevalence of blood splash had poor blood coagulation in terms of prothrombin time (Restall 1980/81), and it was suggested that the common link might be ingestion of excessive amounts of coumarins from pasture. The raised susceptibility to blood splash in unweaned lambs might be a low Vitamin K status because of their milk-based diet. Fourthly, during intense generalised muscle body contractions, such as those during electrical stunning, the venous and arterial systems experience severe external pressure. Squeezing of the veins results in large rises in venous pressure, which is transmitted to the capillary system at sites that can be some distance from the contractions. The venules in the capillary bed probably burst where they are weakest, or where venous pressure is particularly high. This referral of pressure, causing distant petechial haemorrhage, has been seen in other contexts when sudden intense pressures have been applied to veins (French & Callender 1962). Engorgement of the venous circulation would presumably exaggerate this effect.

It is not clear whether blood splash could be due to a direct effect of electrical current on blood vessels, but it seems unlikely. Electrical stimulation of tissues, even at low currents (e.g. 20 µA), will promote extravasation of blood cells from the capillary bed, but this is an inflammatory response and is slower than the time available under slaughtering conditions (Nanmark *et al* 1985). Leakage permitted by electroporation would only occur in the track of an applied current, but since current pathways are not properly understood it is not possible to conclude whether this mechanism is important.

It is well recognised in the broiler processing industry that high frequency currents result in fewer birds with engorged wing veins and wing haemorrhages in comparison with low frequencies (50 or 60 Hz). This has recently been confirmed for turkeys (Wilkins & Wotton 2002), and it was found that the effects of high frequency electrical stunning on breast meat pH fall and quality were minor. High frequency electrical stunning resulted in fewer carcases with broken coracoid and furculum bones, and a lower prevalence of haemorrhages in the meat at these sites. Bleeding efficiency is greater with high frequencies, and the prevalence of cardiac arrest at stunning is lower (Mouchonière *et al* 1999).

Bloody pygostyles can be an unsightly blemish in poultry. McNeal *et al* (2003) found that one way of reducing this problem was to decapitate the birds after stunning, instead of using the normal neck cutting method. Decapitation after electrical stunning also had the advantage that the body lost physical activity sooner after cutting. Evidently, disruption of neurotransmission through the spinal cord led to earlier termination of the convulsions. Gregory *et al* (1999) found in a limited trial that when the prevalence of blood spots in breast muscle was high, it could be reduced by performing a ventral neck cut instead of the conventional dorsal cut. Head only stunning results in breast muscle haemorrhages at the humerus-coracoid joint, whereas with whole body stunning the haemorrhages tend to be in the middle of the muscle (Hillebrand *et al* 1996).

Bleeding efficiency and bleeding rate at sticking are influenced by the factors listed in Table 1. A cardiac arrest at the start of bleeding will slow the rate of blood loss, and in some situations it can result in less blood loss, but this is not an inevitable consequence of inducing a cardiac arrest during electrical stunning (Gregory 1998). Velarde *et al* (2003) showed that lambs that were hoisted and bled without being stunned, released less blood from the sticking wound than lambs that were electrically stunned (250 V, 50 Hz, 3 s), hoisted and then stuck. A likely explanation is that the muscle contractions associated with electrical stunning forced blood away from skeletal muscle towards the vessels in the thorax and abdomen. The implication is that bleeding efficiency in animals slaughtered without stunning is poorer by comparison with animals bled following electrical stunning. The role of severing the vagus nerves at sticking on subsequent bleeding efficiency and residual blood in the carcass has not been examined, but it is known that vagal severance affects the distribution of blood flow in different organs and it reduces the blood pressure and cardiac output responses during haemorrhage (Schertel *et al* 1991). This could have implications for different sticking methods.

Head to back stunning has fallen from favour since its successful introduction in the 1980s. It is not compatible with Halal market requirements and so it is no longer widely used for lambs in New Zealand or Australia. There are still some pig abattoirs using head to back stunning, and unlike the situation in lamb, it does not seem to reduce or prevent blood splash in pigs. Channon *et al* (2003) reported that the haemorrhages following head to back stunning in pigs were not always due to broken vertebrae.

Table 1. Factors affecting bleeding rate or bleeding efficiency at sticking

- Blood vessels that are severed
- Size and patency of the sticking wound
- Cardiac arrest at stunning
- Orientation of the carcass - positioned horizontally or vertically
- Vasodilatation or vasoconstriction in the capillary bed
- Tonic muscle contractions squeezing blood capillaries and vessels
- Clonic activity causing movement of blood towards the sticking wound

Religious slaughter

The welfare issues during slaughter without stunning include the stress of restraint, whether the cut is painful, and whether the animal experiences undue distress whilst it is bleeding out. Inverted restraint has been replaced by upright restraint in some countries, and it is worth considering the evidence behind this change. Over the years, six methods have been used for restraining cattle during Shechita. They are casting with a rope, hoisting by a hindleg, restraint in a straddle conveyor or restraining (V-shaped) conveyor, half inversion in a rotary pen, full inversion in a rotary pen, and restraint whilst standing upright. Koorts (1991) compared the prevalence and severity of struggling in over 1,500 cattle that were either inverted in a casting pen and subjected to Shechita, or were held in the same pen and stunned whilst in an upright position. The prevalence and severity of struggling was graded subjectively by a panel from the first attempt at loading the casting pen either up to the time the animal was stunned, or up to the time of Shechita. The system using stunning was quicker and involved less struggling (Table 2). 4% of the animals due to be killed by Shechita escaped from the casting pen, either because they were oversize or because they were frantic. 9% of the cattle subjected to stunning had to be restunned. In 15% of the cattle, more than one attempt was made at tipping them to the inverted position. A comparable study was conducted by Dunn (1990). The behaviour of cattle in a casting pen was compared with that in an upright pen. The duration of struggling was shorter lasting in the upright pen (1 s *vs.* 11 s, $p<0.001$), the number of vocalisations was higher, and serum cortisol concentrations were greater. Van Oers (1987) found that when head restraint was applied after an animal was inverted, there was more vigorous struggling in comparison with head restraint before inversion. Studies on blood gas tensions indicate that the changes likely to occur during inversion for Shechita are not severe enough to cause serious respiratory embarrassment (Wagner *et al* 1990). Two disadvantages in using upright restraint are that the cut has to be made upwards instead of downwards, and this can be more awkward. Secondly, the Shochet is more likely to get covered with blood because of his position relative to the cut.

Table 2. Average time spent in the casting pen and prevalence of stressed behaviour before stunning or Shechita. After Koorts (1991)

Category	**Average time spent in the casting pen before stunning or Shechita s**				**Prevalence of stressed behaviour %**	
	Secular	*n*	*Shechita*	*n*	*Secular*	*Shechita*
Calm	7	1,085	33	511	69.4	31.4
Nervous	14	418	62	868	26.7	53.3
Wild	22	58	81	208	3.7	12.8
Frantic	35	2	99	41	0.1	2.5

The likely physiological events occurring when a neck is cut in the unanaesthetised state have been discussed by Gregory (2004). In summary, when the neck is cut with a knife there will be direct activation of neurones by the blade as it transects the nerves. This produces an intense but brief injury discharge in the afferent nerves. Thereafter the cut end of the nerves is depolarised and unable to respond to further stimuli. The afferent pathways that are severed serve a range of functions including pain, cold, heat, kinaesthesia, itch, and stretching or distortion of the skin. The sensations produced during the injury discharge is likely to be an amalgam of all such inputs, and the overall effect is likely to be a sense of shock, comparable to an electric shock. There is no reason to assume that one sensation (such as pain or cold) will over-ride all the other sensory input when the nerves are being cut. Subsequently, undamaged nerve endings in the neck wound could respond if stimulated or disturbed, and so the way the wound is managed before consciousness is lost, could be important in determining whether there is pain. Wound management has not been studied in any detail during Shechita.

Barnett & Cronin (in press) have performed an important study on time to loss of consciousness in 41 broilers during Shechita. The birds were taken from the shochet as soon as the cut was made, and placed on their feet on the floor. The time to loss of posture was recorded, and in this situation, this should be a good indicator of loss of balance associated with impaired consciousness. On average the time to loss of posture was 14 sec, and the range was 8 to 26 sec. The implication is that some birds could be fully conscious for up to 26 sec following the cut.

Gas stunning

In some countries, poultry waterbath electrical stunners are being replaced by gas stunning units. Gas stunning is being promoted because it results in less blood spots in the meat and fewer haemorrhages on the surface of the carcass. Five gas stunning methods are being used commercially and they differ in the gas composition. Two methods are used in the UK; 60% argon + 30% CO_2 and less than 2% O_2 using Ar in air. The anoxic method (less than 2% O_2 is falling from favour because of the severity of the carcass convulsions and the cost of Ar. In mainland Europe a mixture of 40% CO_2 + 30% O_2 + 30% N_2 is used for induction of unconsciousness, followed by 80% CO_2 + 20% N_2 for killing. This method is being promoted by Stork PMT. In Japan and Italy, 40% or more CO_2 is applied for over a minute. In the Italian system the birds are lowered into a well containing a gradually increasing CO_2 concentration, with a final concentration of 60% or more CO_2. In the Japanese system the birds are suspended on shackles which are conveyed through the CO_2 unit. The argon-CO_2 method produces greater physical activity as the bird dies in comparison with the Stork method (Gerritzen *et al* 2000), and this is reflected in a slightly faster rate of post-mortem muscle glycolysis in breast muscle (Savenije *et al* 2002a). Whether the accelerated glycolysis is a disadvantage depends on how the carcasses are managed. If they are promptly chilled, it should not be a problem, but where this is not possible, it could result in firmer, if not tougher, breast meat.

There is some debate at the moment as to which of these gas mixtures is most humane. The primary concern is about breathlessness before loss of consciousness. It is recognised that in the human, CO_2 induces a sense of breathlessness with dypnoea. Whereas, hypoxia is not a potent stimulus of breathlessness and dypnoea (Manning and Schwartzstein 1995). During gas stunning the EEG can be divided into three phases. In phase 1 there is normal activity which lasts for 5 to 10 s. In phase 2 the amplitude of the EEG is reduced, and in some birds there is an increase in frequency. It is during this phase that consciousness starts to fail. In phase 3 the EEG is suppressed. Gasping in a standing bird during phases 1 and 2 is a concern from the animal welfare perspective as it indicates breathlessness whilst the bird is conscious. Coenen *et al* (2000) did not observe any intense gasping during phase 1 when comparing 40% CO_2 + 30% O_2 + 30% N_2 with 40% CO_2 + 15% O_2 + 45% N_2. During phase 2, there was less gasping in the higher O_2 mixture. The birds collapsed towards the end of phase 2, and there were no differences between the treatments in time to collapse. This work is not conclusive, because of the limited number of birds in each treatment (four), but as a preliminary finding it raised the possibility that there could be welfare advantages in supplementing CO_2 with O_2.

Some of the work by McIntyre *et al* (in preparation) supports the view that there could be advantages in supplementing CO_2 with O_2. They found that there was less gasping following a ten second exposure to 40% CO_2 + 30% O_2 + 30% N_2 in comparison with 40% CO_2 in air. However, there was no difference in the prevalence of gasping between 40% CO_2 + 30% O_2 + 30% N_2 and 40% CO_2 + 60% N_2. In other words, there was less gasping following 40% CO_2 in N_2 in comparison with 40 % CO_2 in air. More importantly, they found that 25% CO_2 in either air or N_2 resulted in considerable gasping in comparison with any of the 40% CO_2 mixtures. The time to collapse and loss of consciousness is longer with lower concentrations of CO_2.

The work by Raj and by Lambooij indicate that there are welfare advantages from using very low levels of oxygen, or a low (30%) CO_2 in combination with hypoxia, in comparison with 40% CO_2 + 30% O_2 + 30% N_2. Lambooij *et al* (1999) showed that before physical collapse, the birds subjected to 40% CO_2 + 30% O_2 + 30% N_2 showed 9 gasps per bird, birds subjected to 30% CO_2 + 60% Ar showed 3 gasps per bird, and those inhaling 90% Ar in air were almost gasp-free (all the treatments were significantly different from each other, $p < 0.05$). In addition the times to physical collapse were 32, 17 and 16 s respectively, and the 40% CO_2 + 30% O_2 + 30% N_2 treatment was significantly longer than the other treatments ($p< 0.05$). This strongly suggests that breathlessness is a greater problem with the 40% CO_2 + 30% O_2 + 30% N_2 method in comparison with the UK method (30% CO_2 + 60% Ar).

Raj *et al* (1998) examined the rate of induction during 40% CO_2 + 30% O_2 + 30% N_2 and 30% CO_2 + 60% Ar, in terms of the time to EEG suppression and the time to loss of somatosensory evoked potentials in the EEG. The 40% CO_2 + 30% O_2 + 30% N_2 mixture was slower acting than the 30% CO_2 + 60% Ar method. Whether this is important depends on the relative unpleasantness of the two systems. Since Coenen *et al* (2000) observed more intense gasping during the relatively long phase 2 with the 40% CO_2 + 30% O_2 + 30% N_2 mixture compared with 30% CO_2 + 60% Ar, it is thought that the CO_2-Ar method could be more humane. Here again the number of birds in each treatment was very small. Further work is needed using larger numbers of birds, before we conclude which method is more humane.

Headshaking is sometimes used when monitoring the effects of gas stunning, but it is a confusing indicator. In other situations, chickens perform headshaking when they have an irritation such as ear mites, or when consciousness is beginning to be clouded during an intravenous infusion of pentobarbitone. In the context of gas stunning, it is not clear whether headshaking is an indicator of irritation or failing consciousness. The time to loss of posture (physical collapse) is a better indicator of failing consciousness (Mohan Raj and Gregory 1990a). It has been found to coincide with the onset of a high amplitude low frequency waveform in the EEG during anoxic stunning, and with the onset of suppression in the EEG during 31% CO_2 + 2% O_2 stunning in hens (Mohan Raj *et al* 1991; 1992). Convulsions are not usually a cause for concern from the welfare perspective as somatosensory evoked responses are lost and a high amplitude low frequency EEG waveform has set in by the time they occur (Mohan Raj *et al* 1990; Forslid 1987). The convulsions occur when somatomotor activity in the brain is no longer being controlled by activity from higher centres, and so they are a sign of neurological impairment.

Practical experience indicates that the convulsions associated with the 60% argon + 30% CO_2 cause more wing damage than the Stork system. The argon-CO_2 system is also more expensive in terms of gas cost, and it has been claimed that the engineering associated with this system introduces a longer delay in exposure to the final stunning concentration of the gas, and this could slow the onset of unconsciousness.

Practical experience has also shown that pork quality defects can be reduced by using gas stunning in place of electrical stunning. This was confirmed by Channon *et al* (2003) in a study which compared 1.3 A for 4 s with 90% CO_2 for 103 s. It was found that the prevalence of PSE meat and blood splash were lower with gas stunning. The reduction in PSE meat, however, was not reproducible between studies. Anoxic stunning using Ar has been evaluated in pigs. It produced very severe carcass convulsions, but the kicking can be reduced by adding CO_2 to the mixture (Raj, 1999). The concentration of CO_2 that suppresses convulsions can be critical (Mohan Raj and Gregory 1990b)

CONCLUSIONS

Based on the information examined when preparing this review, it is recommended that the following should be considered as future aims. The effect of captive bolt stunning on the presence of BSE prion in beef needs to be examined. If the prion is present in meat, and it is decided to use electrical stunning in place of the captive bolt, the next requirement will be to develop methods for preventing the blood splash that is caused by electrical stunning. We need to determine which of the main gas stunning systems used for poultry are acceptable from the humane standpoint. Work is in-hand in the UK, which should help meet this aim, and once that work has been published, it should be possible to reach a decision. Further development and extension is required on fish stunning methods.

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