An HSUS Report: The Welfare of Birds at Slaughter

Sara Shields, Ph.D.,[*] and Mohan Raj, Ph.D.[†]

Abstract

The customary slaughter method of birds killed for human consumption involves the stunning of several live birds at one time using electrical water baths supplied with constant voltages. The birds are hung upside-down on shackles prior to conveyance through the electrified bath. This system, which is used globally, is increasingly under scrutiny as research suggests that it can be both inhumane and ineffective. Scientists have demonstrated that handling, inversion, and shackling are traumatic and stressful to birds and that shackling itself may be painful. In some cases, birds may also receive painful pre-stun electric shocks. There is growing evidence that the existing electrical water-bath stunner settings, including those used in U.S. slaughter plants, may not render birds immediately unconscious. Further, birds may miss the stunner completely and remain conscious when their throats are cut and possibly when they reach the scald vat. Since the existing, constant voltage, electrical water-bath systems that involve stunning several birds simultaneously are increasingly considered inhumane, alternative technologies that use gas mixtures to render birds unconscious have been developed to improve animal welfare. To date, the most effective and least aversive method of stunning birds prior to slaughter is Controlled Atmosphere Killing (CAK), which rapidly and efficiently gasses birds while they are in transport crates.

Introduction

In 2007, more than 9 billion birds were slaughtered for food in the United States alone.[1] The vast majority, overwhelmingly chickens,[‡] are first hung upside-down on metal shackles by their legs and then stunned using an electrified water-bath system before they are killed. Stunning is practiced in order to render birds unconscious and insensible, and to immobilize them before slaughter.[2,3] However, there is growing concern that stunning several birds at any one moment using an electrified water bath supplied with a constant voltage is inhumane, as birds experience stress and pain before, during, and sometimes after this process.

Newer systems, including Controlled Atmosphere Stunning (CAS) and Controlled Atmosphere Killing (CAK) methods employing naturally occurring gases, are increasingly seen as better alternatives for improved animal welfare, worker conditions, and carcass quality.[§] Despite the fact that birds make up more than 95% of all land animals slaughtered for food in the United States,[4,5] at present, the U.S. Department of Agriculture (USDA) does not include them under the protections of the Humane Methods of Slaughter Act of 1958.[6]

---

[*] Dr. Shields serves as a consulting farm animal welfare scientist for the Humane Society of the United States.
[†] Dr. Raj is a Reader in Farm Animal Welfare at the University of Bristol, School of Veterinary Science, and the world's leading expert on the slaughter of birds for human consumption.
[‡] As chickens are the species slaughtered in the greatest number both globally and in the United States, they will be the focus throughout this paper, although some discussion of the welfare of turkeys during slaughter will also be included.
[§] The terms CAS and CAK are sometimes used interchangeably, but it is imperative that birds do not regain consciousness while on the shackle line. Therefore, CAK systems, which eliminate this potential, are highly preferred and will be the focus throughout this paper.

Electrical Water-Bath Stunning

Multiple-bird electrical water-bath stunning is the most common pre-slaughter stunning method under commercial conditions where large throughput rates are required—i.e., in countries where poultry slaughter and processing are partially or fully mechanized. Most birds arrive at the slaughter plant in transport crates (or modules) on trucks, are unloaded onto a conveyer belt, hung upside-down in metal shackles, and conveyed through the electrical water-bath stunner, their heads passing through the electrically charged water. The animals are then killed by automated knife cut to the throat and subsequent exsanguination. Following the bleed-out process, birds enter the scald tank in preparation for the next step, mechanical plucking of feathers. The United States has one of the fastest throughput rates, with some line speeds as fast as 140-180 birds per minute.[7]

When birds pass through the electrified water bath, current flows in the direction of head to feet, through the whole body towards the shackle line, which is grounded (in contact with the earth). When correctly applied, electrical stunning stimulates the brain with an electric current of sufficient magnitude to induce generalized epilepsy and is thought to be accompanied by unconsciousness and insensibility.[8] However, there are many welfare problems associated with the process of uncrating and shackling live birds, and the operation of existing multiple-bird electrical water-bath stunning technology. These bird welfare concerns are global in nature, applicable to all parts of the world, including the United States, where chicken slaughter is highly mechanized.

Uncrating

In developed countries, chickens are transported to processing plants in one of two types of modules. In one system, common in the United States, birds are tipped out of their transport crates upon arrival at the slaughter plant. During this process, forceful ejection of birds by "thumping" the modules or removing uncooperative individuals with a metal bar can cause bruising and lacerations.[9] Additionally, if chickens are dumped at a faster rate than hanging operators can shackle them, crowding and smothering on the supply belt can occur.[10] The process of removing birds from crates is undoubtedly traumatic, and birds are likely to experience fear and distress.

Shackling

Prior to electrical water-bath stunning, chickens must be shackled. While metal shackles are uniform, the leg sizes of chickens vary. Hanging operators may use considerable force to pull thick shanks into narrow shackles,[11,12] and birds may struggle violently if their legs do not fit properly.[13] Bruising of the surface of leg muscles occurs.[14] Tight-fitting shackles may provide good electrical contact between the legs and metal shackles but increase the severity of the pain associated with shackling. Evidence that shackling, in general, is painful is based on the presence of nociceptors (pain receptors) in the skin over the legs of birds and the close similarities between birds and mammals in nociception.[15,16] This pain is likely to be worse in birds suffering from diseases or abnormalities of leg joints or leg bones,[17,18] especially those with dislocated joints or bone fractures induced by rough handling during catching, crating, and uncrating.[19] Moreover, hanging upside-down is a physiologically abnormal posture for chickens. Handling, inversion, and shackling are traumatic and stressful, as reported in multiple studies that measured physiological indicators of stress.[20,21,22,23] Because of this, approximately 90% of birds flap their wings vigorously,[24] which may lead to dislocated joints and broken bones.[25]

Pre-Stun Electric Shocks

It is well-documented in the scientific and trade literature that some birds inadvertently experience painful electric shocks prior to being stunned in the electrified water bath.[26,27,28,29,30] This can happen when a bird's leading wing makes contact with the water before the head or if wing-flapping occurs at the entrance to the stunner.[31] Turkeys are especially prone to pre-stun shocks,[32] because their wings hang lower than their heads when hung inverted on a shackle.[33] In a survey of six different turkey slaughter plants in the U.K., pre-stun electric shocks were observed in five facilities.[34] In this study, the average number of turkeys receiving electric

shocks prior to stunning was 43%, with some plants reaching up to 87%. In some slaughter plants, pre-stun shocks occurred because the ramp at the entrance to the stun bath was electrically live,[35] although modifications to the entry ramps of chicken stunners may prevent overflow of electrically charged water.[36] However, the prevalence of such entry ramp designs in commercial slaughter plants globally, including within the United States, is not known. It has been suggested that fast line speeds are less likely to produce pre-stun shocks in turkeys, because the wing and head are immersed in the water bath together,[37] yet faster line speeds, as discussed herein, present separate welfare concerns.

Ineffective Stunning

Ineffective stunning of birds in the electrical water-bath system is a global concern. Recent scientific evidence published in 2006 and multiple studies conducted over the preceding few decades suggest that electrical water-bath stunning may not be instantaneous or effective in all the birds. Although it is theoretically possible to induce immediate unconsciousness using electricity of sufficient magnitude, evidence that this occurs in commercial practice is lacking, and the research published in 2006 suggests that the electrical settings currently in use in U.S. slaughter plants, which are becoming used more commonly in the rest of the world, may not render all birds immediately unconscious.[38,39] This is mainly because the precise settings needed to produce an instantaneous state of unconsciousness and insensibility are not easily achieved as control of all the biological and electrical variables in water-bath stunners is difficult.[40]

The criteria used to evaluate the effects of electrical stunning on birds also raise concerns. For example, brain functioning in sheep and pigs following electrical stunning has been investigated experimentally using electroencephalogram (EEG) recordings. Their EEG activity resembles grand mal epilepsy followed by a flat or isoelectric phase indicating unconsciousness.[41] However, scientific literature suggests that the EEG recordings of chickens following electrical stunning differ from those of mammals in that the epileptic activity more closely resembles a petit mal seizure, which is a milder form of epileptic attack in humans. These kinds of seizures are not associated with immediate unconsciousness in humans, leaving open the possibility that electrical stunning does not produce immediate unconsciousness in all birds.[42,43,44,45] Because the brain of a chicken responds to electrical stunning differently than a human's, however, the subjective experience of the bird during a petit mal seizure may also differ. When the occurrence of an epileptiform EEG recording is followed by a quiescent phase, this is thought to be a reliable indicator of unconsciousness and insensibility, and is used in studies of electrical stunning as a measure of the effectiveness of the stun.[46,47]

Although the electrical parameters of stun baths at poultry slaughter plants vary widely,[48,49] research suggests that commonly used settings in U.S. facilities may be inadequate to consistently produce an effective stun in all the birds. The typical wave form, pulse width, frequency, and current settings used in the United States are based on achieving good carcass and meat quality rather than on scientific evidence that they effectively produce unconsciousness and insensibility in every bird. Most of the U.S. broiler chicken industry implements a form of electrical stunning that involves application of a low current setting with a high frequency pulsed direct current (DC) and a reduced (short) pulse width.[50,51,52,53] Depending on the length of the water bath and the line speed,[54] the duration of the electric stun usually lasts 10-12 seconds.[55] The U.S. stunners may be set at 10-28 volts, delivering 10-45 mA per bird, and the frequency of the current varies between 350-500 Hz.[56,57,58] Although precise control of each of these electrical settings relative to the others is important, specific stun settings necessary for an effective and immediate stun are not mandated in the United States.

There has been very little research into the effectiveness of electrical settings commonly used in stun baths at U.S. poultry slaughter plants, but the results of research published in 2006 demonstrate that the parameters used might not render birds immediately unconscious or may not stun them effectively. Work at the University of Bristol's School of Clinical Veterinary Science by co-author Mohan Raj and his colleagues has demonstrated that the sine wave alternating current (AC) is more effective at producing EEG recordings indicative of unconsciousness and insensibility than the pulsed DC used in the United States.[59] The efficacy of stunning decreases as frequency increases,[60] and using either AC or DC, the amount of current necessary for an effective stun increases with the frequency of the current. Using a pulsed DC, it was found that electrical frequencies

above 200 Hz (as commonly found in U.S. slaughter plants) would require an average current greater than 200 mA in order to consistently induce epileptiform activity in EEG recordings.[61] This current is far greater than the 10-45 mA per bird often found in U.S. facilities.

Of further concern is that the pulse width of the DC is also an important factor affecting the likelihood that a stun will be effective. While longer pulse widths are more likely to produce epileptic EEG recordings, reduced pulse widths are common commercially.[62]

There is an inherent conflict between the requirement for effective electrical water-bath stunning and the production of a high-quality carcass and meat free of defects. While the probability of inducing an effective stun decreases as the frequency setting increases, low frequency settings cause intense muscle contraction and consequent rupture of small blood vessels in the skin and/or flesh, causing carcass defects that lead to downgrading.[63] Therefore, higher stunning frequencies (> 300 Hz) have become more prevalent[64] in U.S. slaughter plants[65,66] to ensure carcass and meat quality, despite the existing potential for an ineffective stun and/or for the bird to recover consciousness following stunning. However, even low frequency pulsed DC settings are questionable on animal welfare grounds, because some birds will experience cardiac arrest at stunning, yet fail to show EEGs indicative of effective stunning.[67,68] In general, there is an apparent conflict between bird welfare and meat quality under existing multiple-bird, electrical water-bath stunning, which cannot be resolved due to the complexity and inherent problems with the systems.

Induction of seizures (convulsions), rather than neurophysiological evidence (such as EEG recordings of generalized epilepsy), have been used to justify electrical stunning variables used in the broiler chicken industry.[69] In one study carried out in the U.K. that examined the effects of various current levels, all broiler chickens experienced seizures, whether or not they showed neurophysiological signs of unconsciousness and insensibility.[70] Similarly, in another study, all birds exposed to an average current of 44 mA developed spasms (also referred to in the literature as tremors or seizures) followed by complete muscle relaxation, whether or not their EEG recordings indicated unconsciousness.[71] The unavoidable conclusion one could draw from these results is that the existing electrical water-bath stunning procedures may induce seizures in conscious birds, which is potentially an extremely painful procedure.

The water bath may contain up to 20 birds at any one time.[72] In a constant voltage multiple-bird stunner, as is used commercially, the total current equals the sum of the currents flowing though each bird individually.[73] Variation in electrical resistance or impedance in the current pathway caused by natural variability among birds causes differences in the amount of current that individual birds receive as they pass through the water bath.[74,75,76] Bird variation can be due to many factors, including body size, body muscle and fat content, and plumage condition (e.g., whether the feathers are wet, dry, or dirty), depth of immersion, and the tightness of shackles.[77,78,79] Some birds do not receive a current of sufficient magnitude to stun them effectively.[80] Electrical variables also affect current flow. The mineral content, dirt, and brine concentration all affect the conductivity of the water bath.[81,82] Stunning birds using a multiple-bird electrified water-bath system is a complex task, and it is extremely difficult, if not impossible, to adequately control the process.[83] Therefore, improper stunning occurs with alarming frequency;[84] one study using an average current level that is common in U.S. slaughter plants (44 mA) showed that only 36% of chickens had EEGs indicative of effective stunning.[85]

Indeed, it is the current, rather than the voltage, that is the important factor for inducing an effective stun.[86] When the voltage is held constant, the amount of current delivered to each individual bird in the water-bath stunner is inversely related to the bird's resistance. As well, there is a delay in the passage of the correct current amount through the brain of the bird as the current rises, depending upon the electrical impedance or resistance in the pathway, from zero to the maximum level.[87] Therefore constant voltage stunners are inherently less efficient in inducing immediate unconsciousness.

At the low voltage and current levels used in the United States, this period during which the electrical impedance breaks down and unconsciousness is induced could be extremely painful.[88]

To overcome the problem of variable electrical impedance in multiple-bird water-bath stunners, constant current stunners have been developed in the U.K. but have not been implemented in the slaughter plants. These stunners control current flow through individual birds by electrically isolating each one to ensure that all birds in a multiple-bird water-bath stunner receive the minimum current needed for an adequate stun.[89,90] By controlling the current rather than the voltage, stunning can be acheived in 0.25 seconds, overcoming the delay in inducing unconsciousness that is characteristic of constant voltage systems.[91] However, because shackles are only 15 cm (5.9 in) apart on the line and because processing speed can be as high as 220 chickens per minute, there is considerable doubt that it is possible to electrically isolate each bird for long enough to deliver the pre-set current. As such, commercial application of these systems has been limited.[92,93]

Birds may not be adequately stunned if they flap their wings when entering the stunner, delaying or interrupting contact with the electrified water bath. When the depth or duration of the stun is not sufficient, birds may experience pain and distress when they reach the killing (neck-cutting) machine and during at least part of bleed-out.[94,95] This is clearly unacceptable from humanitarian and bird welfare standpoints.

Over the past few decades, researchers and veterinarians working independently have suggested that electrically stunned birds may not be unconsciousness at all when shocked in an electrified water bath, but rather in a state of electrical paralysis.[96,97,98,99] Prolonged application (three seconds or more) of insufficient current level may cause immobilization and prevent birds from displaying outward signs of pain, without rendering them unable to experience pain, stress, or discomfort.[100,101] Because birds may experience electrically-induced paralysis, seizures, and cardiac arrest while still conscious and because stunning may be delayed and/or ineffective, the existing electrical water-bath stunning system in and of itself cannot be considered humane.

Missing the Stun Bath

Some birds are conveyed through the stunner without ever making contact with the electrified water bath itself, which is a global welfare problem. This can happen if birds struggle and lift their heads, if the height of the stunner is not correctly adjusted, or if birds are too short to reach the water bath.[102,103,104] Egg-laying hens whose productivity has waned, commonly referred to as "spent," are especially prone to missing the stun bath as they are more likely to struggle in the shackles.[105,106] In 2007, one of the top disease challenges facing poultry veterinarians in the United States was Runting Stunting Syndrome (RSS) in broiler chickens. RSS-affected flocks have poor growth and lack uniformity in size, hindering the slaughter process,[107] possibly worsening the problem of small birds missing the stunner. Birds missing the stunner remain fully conscious when their necks are cut. There are no public records of the number of birds who miss the stunner in U.S. poultry slaughter plants. Advances in electrical water-bath design, such as the installation of rump bars to limit movement and breast rub pads to calm birds, may better prevent birds from missing the stun bath,[108] yet smaller birds (especially runts) may still reach the killing machine while fully conscious. Additionally, as RSS-affected birds would remain physically in contact with the adjacent birds passing through the stunner, the possibility that the RSS birds would receive painful electric shocks in a conscious state could not be ruled out.

Neck-Cutting

Effectively stunned birds who have not undergone cardiac arrest at stunning must be killed quickly, otherwise they will regain consciousness.[109] The duration of a stun is dependent on the amount and frequency of the current.[110] Birds are in danger of regaining consciousness during bleed-out and of entering the scald vat while alive if the neck-cutting procedure is ineffective. A ventral cut, which severs both carotid arteries, is more effective at inducing a rapid death than a neck cut that severs only one carotid artery.[111,112,113] Unlike in the United States, ventral neck-cutting is not always practiced in some countries,[114] and, even in the United States, severance of both the carotid arteries in the necks of different sized birds is not always possible whilst using neck-cutting machines.

Entering the Scald Tank Alive

Occasionally, live birds who were not adequately stunned and/or who missed the killing machine, or who recovered from the stun due to poor neck-cutting practices are live or conscious when entering the scald tank.[115,116,117,118] In the United States, U.K., and many other industrialized countries, a worker is present on the slaughter line to manually cut the throats of birds who miss the automated blade. However, in high-throughput slaughter plants, line speeds can prevent the detection of live birds exiting the killing machine.[119] In U.S. plants with improper supervision, the rate at which birds enter the scald tank while still alive may be as high as 3%.[120] According to the USDA's Food Safety and Inspection Service "Poultry Slaughter Inspection Training" guide, "Poultry that die from causes other than slaughter are condemned under the cadaver category. These birds are not dead when they enter the scald vat. When submerged in the hot water, they drown…."[121] In 2007 more than 1.5 million chickens and turkeys were condemned under this category.[122]

Conclusions: Electrical Water-Bath Stunning

Historically, the development of electrical stunning devices was driven more by the need to facilitate processing and automation of slaughter than by concern for bird welfare.[123] Although water-bath stunning could theoretically produce a state of insensibility rapidly, the complexities of ensuring the correct electrical settings and the conflict between effective stunning and commercial interests in carcass and meat quality largely preclude these conditions in practice. However, the problem of dumping, handling, and shackling conscious birds remains, even if electrical variables could be satisfactorily controlled. Questions about the nature of the state of unconsciousness (or lack thereof) actually produced by electrical water baths raises further concerns about the system. In summary, the existing multiple-bird electrical water-bath stunning systems supplied with constant voltages are inadequate on welfare grounds as they do not ensure the least aversive slaughter possible.

Controlled Atmosphere Killing (CAK)

CAK in transport crates or modules provides higher welfare as it does not require live bird handling at the slaughter plants, hence avoiding the problems associated with dumping,** handling, and shackling live birds. As well, these systems do not risk pre-stun shocks and/or ineffective stunning. In the best CAK systems, birds in transport crates or modules are conveyed through a tunnel filled with increasing concentrations of carbon dioxide (CO_2), inert gases (argon or nitrogen), or a mixture of these gases. With CAK, birds are exposed to lethal concentrations of gases long enough that they are actually killed, rather than simply stunned,[124] whereas with Controlled Atmosphere Stunning (CAS), the gas or gases induce unconsciousness as the birds pass through before they are hung on shackles, while insensible, and conveyed to the killing machine for slaughter. In either system, hanging operators do not shackle the birds until after they exit the gas stunning system, so the birds do not endure the pain, fear, and stress associated with this step in the conventional procedure.

Several different naturally occurring gases are used in CAK and CAS systems, and each has different physiological effects on the birds. Breathable air consists of approximately 21% oxygen (O_2), 78% nitrogen (N), and 1% other gases (primarily argon, but with a small amount of CO_2). When inhaled in high concentrations, the inert gases (argon and nitrogen) cause hypoxia or anoxia, which is oxygen deprivation in the body. The organ most sensitive to a physiologic decrease in blood oxygen levels is the brain, and unconsciousness and eventual death result when the oxygen level is insufficient for normal brain functioning. In contrast, elevated CO_2 levels cause hypercapnia, an increase in CO_2 levels in the blood, which disrupts respiration and normal neuronal function, leading eventually to death.

With CAS, the potential exists for birds to regain consciousness after exiting the gaseous atmosphere while being shackled and conveyed to the neck-cutter, or during bleeding. Therefore, it is imperative that the birds are

** Some gas systems are designed in such a way that birds must still be dumped from their transport crates prior to entering the gas-filled chamber on a conveyer belt. While still retaining many of the welfare advantages of CAK systems, those that move birds through the gaseous atmosphere while they are still in their transport crates are considered optimal.

actually killed, rather than stunned, by the gas or gases.[125] In this way, the use of CAK fully obtains the welfare benefits of the method, as compared to CAS, in which the potential exists for birds to awaken from their unconscious state. Some commercial processors have continued to use the term "Controlled Atmosphere Stunning" even when they have a CAK system in place for various reasons. For example, birds subjected to CAK show residual heart activity for a few minutes after the cessation of other functions such as breathing.

Current Research on the Least Aversive Gas Mixtures

Some of the first research on the use of gas to stun birds was published in the 1950s,[126] and, by the late 1990s, continuing research led to the adoption of the first commercial gas stunning systems.[127] CO_2, a byproduct of the chemical and fertilizer industries, was initially examined in research studies for poultry slaughter plants, because it is easily obtainable and relatively inexpensive. However, interest in the inert gases, including argon and nitrogen, was sparked by human aviation physiology studies, which demonstrated that anoxia-induced unconsciousness is euphoric. It was on the basis of this research that studies into the least aversive gas mixtures began.

Inhalation of the inert gases is thought to be painless, as birds do not demonstrate aversive reactions with initial exposure. In carefully controlled behavior experiments, turkeys and chickens were willing to enter a chamber filled with argon in order to access food.[128,129] In contrast, there are both physiological and behavioral lines of scientific evidence suggesting that CO_2 may be unpleasant and possibly very distressing to inhale, as it is an acidic gas, pungent to inhale at high concentrations.[130,131] Birds have intrapulmonary chemoreceptors that detect CO_2, but are insensitive to hypoxia induced with argon and nitrogen, which are tasteless and odorless. Indeed, they show signs of respiratory distress when exposed to CO_2[132] and will often avoid an atmosphere containing high concentrations of carbon dioxide when tested in behavior experiments.[133,134]

Some scientists, however, contend that there are also problems with the use of inert gases to stun birds. The primary concern is that inert gases cause convulsions as the birds lose consciousness. Convulsions are thought to be reflexive reactions occurring only after the bird has lost consciousness; however, some have questioned this tenet, as discussed below, and argue the thrashing of one bird may frighten or physically harm, albeit briefly, other birds in the vicinity who have not yet lost consciousness. These convulsions can be aesthetically unpleasant to human observers and also involve leg and wing movements powerful enough to throw the bird against the walls of the chamber and against other birds.[135] Further, broken wing bones caused by convulsions reduce the quality of the carcass. For these reasons and because inert gases are not readily available in large quantities or are more expensive to obtain than CO_2, the poultry industry has been reluctant to broadly adopt this gas technology in the United States. In contrast, in the U.K., where the use of inert gases for stunning/killing birds has been approved, it is estimated that more than 75% of turkeys and 25% of broiler chickens slaughtered for human consumption are killed using inert mixtures.[136]

As a possible solution, two-step systems that first render the birds unconscious with a low level of CO_2 followed by a second stage with lethal CO_2 levels are being adopted commercially. Exposure to low concentrations of CO_2 (e.g., 30% by volume in air) does not cause convulsions to the extent that inert gases do and, despite its aversiveness, is thought to have an anaesthetic effect for a variety of species at low levels, reducing pain sensitivity.[137] The humaneness of exposure to low concentrations of CO_2 has been evaluated, and it has been argued that CO_2 levels of 30% or less may not be very much more aversive to inhale than the inert gas argon. This was demonstrated by scientists Bruce Webster and Daniel Fletcher at the University of Georgia in Athens in an experiment requiring hungry hens to enter a gas-filled chamber to access food. Nearly as many hens entered the feeding chamber and lost posture (an early sign of onset of unconsciousness) due to gas exposure when the chamber was filled with 30% CO_2 in air as compared to argon. Based on their analysis of hen behavior during their experiment and other published data, the researchers concluded that any bird welfare advantage of argon is relatively minor.[138] Similar results were found in another study that tested the aversiveness of various gas mixtures by exposing broiler chickens to a 10-second pulse of gas while the birds fed. Dorothy McKeegan, Faculty of Veterinary Medicine at the University of Glasgow, and her colleagues also found, based on the

tendency of chickens to cease feeding during gas delivery over the feed dish, that a low level of CO_2 is only mildly or moderately aversive.[139]

In a series of experiments published in 2007, McKeegan and her colleagues tested several gas mixtures and concluded that a two-step system—using 40% CO_2, 30% O_2, and 30% N in the first phase and 80% CO_2, 5% O_2, and 15% N in the second phase—was best from both an animal welfare and a meat quality perspective.[140,141] Not unexpectedly, behavioral observations at the processor showed that wing-flapping and jumping associated with convulsions were greater in the gas mixture tested that contained argon, and this led to fractured wings and hemorrhages that are considered unacceptable carcass quality problems by some processors. They concluded that the transition to a motionless state was longer but smoother using the 40% CO_2, 30% O_2, and 30% N in the induction phase.[142] A further concern was that a parallel laboratory study was not able to rule out the possibility that the initial vigorous behavioral response to the gas mixture containing argon occurred while chickens were still conscious.[143]

In spite of these concerns, research presented in 2006 and 2008 further evaluated gas aversion from the perspective of the birds themselves. Three different gas mixtures were presented to chickens at a feeding station fitted with gas outlets. The researchers at the Scottish Agricultural College found that the birds, given free choice, preferred to feed in the presence of inert gases, nitrogen and argon, with low CO_2 contents (less than 30% by volume).[144,145] The new studies reinforce the evidence that birds find inert gases less aversive than CO_2 at high concentrations.

Although the precise gas mixture is important, ongoing research should not prevent the poultry industry from adopting CAK technology. Regardless of the gas mixture used, CAK eliminates the problems associated with handling and shackling live birds, painful pre-stun shocks, and variations in current that may or may not adequately render birds insensible. Pending further research that will undoubtedly continue to refine and improve knowledge and understanding of the procedure, many gas mixtures currently provide higher welfare, including argon and nitrogen with less than 2% residual oxygen, and any mixture of argon, nitrogen, or other inert gases with up to 30% CO_2.[146]

Additional Benefits of CAK

In addition to the benefits associated with improved bird welfare, CAK also improves the working conditions for hanging operators. The job of shackling live birds is difficult, as the animals may resist and struggle; dirty, due to aerial dust, feather dander, excrement, and unsanitary working conditions; and environmentally challenging, as live-hang must be performed in low light to quiet the birds. By contrast, when CAK is used, hanging operators do not handle the birds until they are unconscious or killed, thereby eliminating these problems.[††147]

There is also a food safety concern with the use of electrical water-bath systems. When birds are stunned in the electrified water bath, they often defecate into the water.[148] Some birds also inhale the contaminated water as they pass through, risking exposure of internal tissue to pathogens.[149] With the use of CAK, birds are not passed through a water bath, avoiding altogether this food safety concern.[150]

CAK also virtually eliminates carcass quality problems that can occur with electrical water-bath stunning. Poultry processors that have adopted gas technology have claimed that they have better product quality with fewer broken bones, blood spots, and bruising, and better bleed-out.[151,152]

[††] For additional information, see: An HSUS Report: Human Health Implications of Live Hang of Chickens and Turkeys on Slaughterhouse Workers at www.hsus.org/web-files/PDF/farm/HSUS-Human-Health-Report-on-Poultry-Slaughter-Live-Hang-Workers.pdf.

Conclusion

After a comprehensive review of the scientific literature, the Scientific Panel on Animal Health and Welfare, an official advisory body to the European Commission, stated:

> Since welfare is poor when the shackling line and water bath electrical stunning method is used, and birds are occasionally not stunned before slaughter, the method should be replaced as soon as possible. At present, the inert gas stun/killing method is the best alternative.[153]

The existing U.S. standard for electrical stunning of birds killed for human consumption does not conform to the guidelines of the World Organisation for Animal Health (OIE), which recommends as optimum a minimum of 100 mA delivered using 50 Hz sine wave alternating current per chicken.[154]

It is ethically imperative that slaughter be both quick and painless, particularly in countries such as the United States, wherein birds killed for food are not afforded legal protections to govern their welfare at slaughter. Given the current state of pre-slaughter stunning technology, CAK is the method that provides conditions for slaughtering birds with a minimum of avoidable pain and suffering. Further benefits, including better working conditions for hanging operators, avoiding food safety risks, and improved carcass quality, solidify that this technology is strongly preferred to the existing multiple-bird electrical water-bath stunning systems supplied with constant voltages. The OIE has commented positively on novel and higher welfare gaseous stunning and killing methods,[155] and it is imperative that the U.S. industry implement these technologies to improve animal welfare.

---

[1] U.S. Department of Agriculture National Agricultural Statistics Service. 2008. Poultry slaughter: 2007 annual summary. http://usda.mannlib.cornell.edu/usda/current/PoulSlauSu/PoulSlauSu-02-28-2008.pdf. Accessed September 5, 2008.
[2] Craig EW and Fletcher DL. 1997. A comparison of high current and low voltage electrical stunning systems on broiler breast rigor development and meat quality. Poultry Science 76(8):1178-81.
[3] Bilgili SF. 1992. Electrical stunning of broilers—basic concepts and carcass quality implications: a review. Journal of Applied Poultry Research 1(1):135-46.
[4] U.S. Department of Agriculture National Agricultural Statistics Service. 2008. Livestock slaughter: 2007 summary. http://usda.mannlib.cornell.edu/usda/current/LiveSlauSu/LiveSlauSu-03-07-2008_revision.pdf. Accessed September 5, 2008.
[5] U.S. Department of Agriculture National Agricultural Statistics Service. 2008. Poultry slaughter: 2007 annual summary. http://usda.mannlib.cornell.edu/usda/current/PoulSlauSu/PoulSlauSu-02-28-2008.pdf. Accessed September 5, 2008.
[6] U.S. Department of Agriculture Food Safety and Inspection Service. 2005. Treatment of live poultry before slaughter; notice. September 28. Federal Register 70(187):56624-26.
[7] Bilgili SF. 1999. Recent advances in electrical stunning. Poultry Science 78(2):282-6.
[8] Raj M. 1998. Welfare during stunning and slaughter of poultry. Poultry Science 77(12):1815-9.
[9] Shane SM. 2005. Future of gas stunning. WATT Poultry USA 6(4):16-23.
[10] Shane SM. 2005. Future of gas stunning. WATT Poultry USA 6(4):16-23.
[11] Sparrey JM and Kettlewell PJ. 1994. Shackling of poultry: is it a welfare problem? World's Poultry Science Journal 50:167-76.
[12] Gregory NG and Bell JC. 1987. Duration of wing flapping in chickens shackled before slaughter. The Veterinary Record 121(24):567-9.
[13] Parker LH, Bajoie KC, Castille S, Cadd GG, Satterlee DG, and Jones RB. 1997. Sex and shank diameter affect struggling behaviour of shackled broilers. Poultry Science 76(Supplement 1):88.
[14] Raj ABM. 2004. Stunning and slaughter of poultry. In: Mead GC (ed.), Poultry Meat Processing and Quality (Cambridge, U.K.: Woodhead Publishing Ltd.).
[15] Gentle MJ and Tilston VL. 2000. Nociceptors in the legs of poultry: implications for potential pain in pre-slaughter shackling. Animal Welfare 9(3):227-36.

[16] Gentle MJ. 1992. Ankle joint (artc. intertarsalis) receptors in the domestic fowl. Neuroscience 49(4):991-1000.
[17] European Food Safety Authority. 2004. Scientific report of the Scientific Panel for Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods, pp. 125-6. www.efsa.europa.eu/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_report_v2_en1,1.pdf. Accessed September 5, 2008.
[18] Danbury TC, Weeks CA, Chambers JP, Waterman-Pearson AE, and Kestin SC. 2000. Self-selection of the analgesic drug carprofen by lame broiler chickens. The Veterinary Record 146(11):307-11.
[19] Raj ABM. 2004. Stunning and slaughter of poultry. In: Mead GC (ed.), Poultry Meat Processing and Quality (Cambridge, U.K.: Woodhead Publishing Ltd.).
[20] Kannan G and Mench JA. 1996. Influence of different handling methods and crating periods on plasma corticosterone concentrations in broilers. British Poultry Science 37(1):21-31.
[21] Debut M, Berri C, Arnould C, et al. 2005. Behavioural and physiological responses of three chicken breeds to pre-slaughter shackling and acute heat stress. British Poultry Science 46(5):527-35.
[22] Kannan G, Heath JL, Wabeck CJ, and Mench JA. 1997. Shackling of broilers: effects on stress responses and breast meat quality. British Poultry Science 38(4):323-32.
[23] Bedanova I, Voslarova E, Chloupek P, et al. 2007. Stress in broilers resulting from shackling. Poultry Science 86(6):1065-9.
[24] Kannan G, Heath JL, Wabeck CJ, and Mench JA. 1997. Shackling of broilers: effects on stress responses and breast meat quality. British Poultry Science 38(4):323-32.
[25] European Food Safety Authority. 2004. Opinion of the Scientific Panel on Animal Health and Welfare (AHAW) on a request from the Commission related to welfare aspects of the main systems of stunning and killing the main commercial species of animals. www.efsa.europa.eu/EFSA/efsa_locale-1178620753812_1178620775454.htm. Accessed September 5, 2008.
[26] Gregory NG and Bell JC. 1987. Duration of wing flapping in chickens shackled before slaughter. The Veterinary Record 121(24):567-9.
[27] European Food Safety Authority. 2004. Opinion of the Scientific Panel on Animal Health and Welfare (AHAW) on a request from the Commission related to welfare aspects of the main systems of stunning and killing the main commercial species of animals. www.efsa.europa.eu/EFSA/efsa_locale-1178620753812_1178620775454.htm. Accessed September 5, 2008.
[28] Sparrey JM, Kettlewell PJ, Paice MER, and Whetlor WC. 1993. Development of a constant current water bath stunner for poultry processing. Journal of Agricultural Engineering Research 56(4):267-74.
[29] Schütt-Abraham I, Wormuth HJ, and Fessel J. 1983. Electrical stunning of poultry in view of animal welfare and meat production. In: Eikelenboom G (ed.), Stunning of Animals for Slaughter (The Hague, Netherlands: Martinus Nijhoff Publishers, pp. 187-96).
[30] Gazdziak S. 2007. Kill floor improvements: automation on the poultry kill and eviscerating lines is increasing efficiency and product quality. The National Provisioner, December, pp. 66, 68.
[31] Raj ABM. 2004. Stunning and slaughter of poultry. In: Mead GC (ed.), Poultry Meat Processing and Quality (Cambridge, U.K.: Woodhead Publishing Ltd.).
[32] Gregory NG. 1994. Pathology and handling of poultry at the slaughterhouse. World's Poultry Science Journal 50:66-7.
[33] Raj M. 1998. Welfare during stunning and slaughter of poultry. Poultry Science 77(12):1815-9.
[34] Wooton *[sic]* SB and Gregory NG. 1991. How to prevent pre-stun electric shocks in waterbath stunners. Turkeys 39(2):15, 30.
[35] Wooton *[sic]* SB and Gregory NG. 1991. How to prevent pre-stun electric shocks in waterbath stunners. Turkeys 39(2):15, 30.
[36] Bilgili SF. 1999. Recent advances in electrical stunning. Poultry Science 78(2):282-6.
[37] Wooton *[sic]* SB and Gregory NG. 1991. How to prevent pre-stun electric shocks in waterbath stunners. Turkeys 39(2):15, 30.

[38] Raj ABM, O'Callaghan M, and Hughes SI. 2006. The effects of amount and frequency of pulsed direct current used in water bath stunning and of slaughter methods on spontaneous electroencephalograms in broilers. Animal Welfare 15(1):19-24.
[39] Raj ABM, O'Callaghan M, and Knowles TG. 2006. The effects of amount and frequency of alternating current used in water bath stunning and of slaughter methods on electroencephalograms in broilers. Animal Welfare 15(1):7-18.
[40] Boyd F. 1994. Humane slaughter of poultry: the case against the use of electrical stunning devices. Journal of Agricultural & Environmental Ethics 7(2):221-36.
[41] Gregory NG and Wotton SB. 1987. Effect of electrical stunning on the electroencephalogram in chickens. British Veterinary Journal 143(2):175-83.
[42] Raj ABM. 2003. A critical appraisal of electrical stunning in chickens. World's Poultry Science Journal 59(1):89-98.
[43] Gregory NG and Wotton SB. 1987. Effect of electrical stunning on the electroencephalogram in chickens. British Veterinary Journal 143(2):175-83.
[44] Gregory NG. 1986. The physiology of electrical stunning and slaughter. In: Humane Slaughter of Animals for Food Symposium (Hertfordshire, U.K.: Universities Federation for Animal Welfare, pp. 3-14).
[45] Boyd F. 1994. Humane slaughter of poultry: the case against the use of electrical stunning devices. Journal of Agricultural & Environmental Ethics 7(2):221-36.
[46] Raj ABM. 2003. A critical appraisal of electrical stunning in chickens. World's Poultry Science Journal 59(1):89-98.
[47] Raj ABM, O'Callaghan M, and Knowles TG. 2006. The effects of amount and frequency of alternating current used in water bath stunning and of slaughter methods on electroencephalograms in broilers. Animal Welfare 15(1):7-18.
[48] Raj ABM, O'Callaghan M, and Knowles TG. 2006. The effects of amount and frequency of alternating current used in water bath stunning and of slaughter methods on electroencephalograms in broilers. Animal Welfare 15(1):7-18.
[49] Raj ABM. 2006. Recent developments in stunning and slaughter of poultry. World's Poultry Science Journal 62(3):467-84.
[50] Craig EW and Fletcher DL. 1997. A comparison of high current and low voltage electrical stunning systems on broiler breast rigor development and meat quality. Poultry Science 76(8):1178-81.
[51] Wilkins LJ, Wotton SB, Parkman ID, Kettlewell PJ, and Griffiths P. 1999. Constant current stunning effects on bird welfare and carcass quality. Journal of Applied Poultry Research 8(4):465-71.
[52] Raj ABM. 2004. Stunning and slaughter of poultry. In: Mead GC (ed.), Poultry Meat Processing and Quality (Cambridge, U.K.: Woodhead Publishing Ltd.).
[53] Raj ABM, O'Callaghan M, and Hughes SI. 2006. The effects of pulse width of a direct current used in water bath stunning and of slaughter methods on spontaneous electroencephalograms in broilers. Animal Welfare 15(1):25-30.
[54] Wilkins LJ, Wotton SB, Parkman ID, Kettlewell PJ, and Griffiths P. 1999. Constant current stunning effects on bird welfare and carcass quality. Journal of Applied Poultry Research 8(4):465-71.
[55] Sams AR. 2001. First processing: slaughter through chilling. In: Sams AR (ed.), Poultry Meat Processing (Washington, DC: CRC Press, p. 21).
[56] Nunes F. 2007. How to avoid bruising during electrical poultry stunning. Meatingplace.com, May.
[57] Bilgili SF. 1999. Recent advances in electrical stunning. Poultry Science 78(2):282-6.
[58] Gazdziak S. 2007. Kill floor improvements: automation on the poultry kill and eviscerating lines is increasing efficiency and product quality. The National Provisioner, December, pp. 66, 68.
[59] Raj ABM, O'Callaghan M, and Hughes SI. 2006. The effects of amount and frequency of pulsed direct current used in water bath stunning and of slaughter methods on spontaneous electroencephalograms in broilers. Animal Welfare 15(1):19-24.
[60] Raj ABM, O'Callaghan M, and Knowles TG. 2006. The effects of amount and frequency of alternating current used in water bath stunning and of slaughter methods on electroencephalograms in broilers. Animal Welfare 15(1):7-18.

[61] Raj ABM, O'Callaghan M, and Hughes SI. 2006. The effects of amount and frequency of pulsed direct current used in water bath stunning and of slaughter methods on spontaneous electroencephalograms in broilers. Animal Welfare 15(1):19-24.
[62] Raj ABM, O'Callaghan M, and Hughes SI. 2006. The effects of pulse width of a direct current used in water bath stunning and of slaughter methods on spontaneous electroencephalograms in broilers. Animal Welfare 15(1):25-30.
[63] Wilkins LJ, Wotton SB, Parkman ID, Kettlewell PJ, and Griffiths P. 1999. Constant current stunning effects on bird welfare and carcass quality. Journal of Applied Poultry Research 8(4):465-71.
[64] Raj ABM. 2003. A critical appraisal of electrical stunning in chickens. World's Poultry Science Journal 59(1):89-98.
[65] Bilgili SF. 1999. Recent advances in electrical stunning. Poultry Science 78(2):282-6.
[66] Gazdziak S. 2007. Kill floor improvements: automation on the poultry kill and eviscerating lines is increasing efficiency and product quality. The National Provisioner, December, pp. 66, 68.
[67] Raj ABM, O'Callaghan M, and Hughes SI. 2006. The effects of amount and frequency of pulsed direct current used in water bath stunning and of slaughter methods on spontaneous electroencephalograms in broilers. Animal Welfare 15(1):19-24.
[68] Raj ABM, O'Callaghan M, and Hughes SI. 2006. The effects of pulse width of a direct current used in water bath stunning and of slaughter methods on spontaneous electroencephalograms in broilers. Animal Welfare 15(1):25-30.
[69] Raj ABM. 2003. A critical appraisal of electrical stunning in chickens. World's Poultry Science Journal 59(1):89-98.
[70] Raj ABM, O'Callaghan M, and Knowles TG. 2006. The effects of amount and frequency of alternating current used in water bath stunning and of slaughter methods on electroencephalograms in broilers. Animal Welfare 15(1):7-18.
[71] Schütt-Abraham I, Wormuth HJ, and Fessel J. 1983. Electrical stunning of poultry in view of animal welfare and meat production. In: Eikelenboom G (ed.), Stunning of Animals for Slaughter (The Hague, Netherlands: Martinus Nijhoff Publishers, pp. 187-96).
[72] Wilkins LJ, Wotton SB, Parkman ID, Kettlewell PJ, and Griffiths P. 1999. Constant current stunning effects on bird welfare and carcass quality. Journal of Applied Poultry Research 8(4):465-71.
[73] Sparrey JM, Kettlewell PJ, Paice MER, and Whetlor WC. 1993. Development of a constant current water bath stunner for poultry processing. Journal of Agricultural Engineering Research 56(4):267-74.
[74] Kettlewell PJ and Hallworth RN. 1990. Electrical stunning of chickens. Journal of Agricultural Engineering Research 47(3):139-51.
[75] Bilgili SF. 1999. Recent advances in electrical stunning. Poultry Science 78(2):282-6.
[76] Raj M and Tserveni-Gousi A. 2000. Stunning methods for poultry. World's Poultry Science Journal 56(4):291-304.
[77] Boyd F. 1994. Humane slaughter of poultry: the case against the use of electrical stunning devices. Journal of Agricultural & Environmental Ethics 7(2):221-36.
[78] Bilgili SF. 1992. Electrical stunning of broilers—basic concepts and carcass quality implications: a review. Journal of Applied Poultry Research 1(1):135-46.
[79] Kettlewell PJ and Hallworth RN. 1990. Electrical stunning of chickens. Journal of Agricultural Engineering Research 47(3):139-51.
[80] Wilkins LJ, Wotton SB, Parkman ID, Kettlewell PJ, and Griffiths P. 1999. Constant current stunning effects on bird welfare and carcass quality. Journal of Applied Poultry Research 8(4):465-71.
[81] Boyd F. 1994. Humane slaughter of poultry: the case against the use of electrical stunning devices. Journal of Agricultural & Environmental Ethics 7(2):221-36.
[82] Bilgili SF. 1992. Electrical stunning of broilers—basic concepts and carcass quality implications: a review. Journal of Applied Poultry Research 1(1):135-46.
[83] Raj ABM. 2004. Stunning and slaughter of poultry. In: Mead GC (ed.), Poultry Meat Processing and Quality (Cambridge, U.K.: Woodhead Publishing Ltd.).
[84] Boyd F. 1994. Humane slaughter of poultry: the case against the use of electrical stunning devices. Journal of Agricultural & Environmental Ethics 7(2):221-36.

[85] Schütt-Abraham I, Wormuth HJ, and Fessel J. 1983. Electrical stunning of poultry in view of animal welfare and meat production. In: Eikelenboom G (ed.), Stunning of Animals for Slaughter (The Hague, Netherlands: Martinus Nijhoff Publishers, pp. 187-96).
[86] Sparrey JM, Kettlewell PJ, Paice MER, and Whetlor WC. 1993. Development of a constant current water bath stunner for poultry processing. Journal of Agricultural Engineering Research 56(4):267-74.
[87] Raj ABM. 2004. Stunning and slaughter of poultry. In: Mead GC (ed.), Poultry Meat Processing and Quality (Cambridge, U.K.: Woodhead Publishing Ltd.).
[88] Raj ABM. 2004. Stunning and slaughter. In: Perry GC (ed.), Welfare of the Laying Hen (Wallingford, U.K.: CAB International).
[89] Wilkins LJ, Wotton SB, Parkman ID, Kettlewell PJ, and Griffiths P. 1999. Constant current stunning effects on bird welfare and carcass quality. Journal of Applied Poultry Research 8(4):465-71.
[90] Sparrey JM, Kettlewell PJ, Paice MER, and Whetlor WC. 1993. Development of a constant current water bath stunner for poultry processing. Journal of Agricultural Engineering Research 56(4):267-74.
[91] Sparrey JM, Kettlewell PJ, Paice MER, and Whetlor WC. 1993. Development of a constant current water bath stunner for poultry processing. Journal of Agricultural Engineering Research 56(4):267-74.
[92] Raj ABM. 2004. Stunning and slaughter of poultry. In: Mead GC (ed.), Poultry Meat Processing and Quality (Cambridge, U.K.: Woodhead Publishing Ltd.).
[93] Bilgili SF. 1999. Recent advances in electrical stunning. Poultry Science 78(2):282-6.
[94] Gazdziak S. 2007. Kill floor improvements: automation on the poultry kill and eviscerating lines is increasing efficiency and product quality. The National Provisioner, December, pp. 66, 68.
[95] Raj M and Tserveni-Gousi A. 2000. Stunning methods for poultry. World's Poultry Science Journal 56(4):291-304.
[96] Heath GBS, Watt DJ, Waite PR, and Ormond JM. 1981. Observations on poultry slaughter. The Veterinary Record 108(5):97-9.
[97] Raj ABM. 2004. Stunning and slaughter. In: Perry GC (ed.), Welfare of the Laying Hen (Wallingford, U.K.: CAB International).
[98] Bilgili SF. 1999. Recent advances in electrical stunning. Poultry Science 78(2):282-6.
[99] Schütt-Abraham I, Wormuth HJ, and Fessel J. 1983. Electrical stunning of poultry in view of animal welfare and meat production. In: Eikelenboom G (ed.), Stunning of Animals for Slaughter (The Hague, Netherlands: Martinus Nijhoff Publishers, pp. 187-96).
[100] Raj ABM. 2004. Stunning and slaughter. In: Perry GC (ed.), Welfare of the Laying Hen (Wallingford, U.K.: CAB International).
[101] Bilgili SF. 1999. Recent advances in electrical stunning. Poultry Science 78(2):282-6.
[102] Raj ABM. 2004. Stunning and slaughter of poultry. In: Mead GC (ed.), Poultry Meat Processing and Quality (Cambridge, U.K.: Woodhead Publishing Ltd.).
[103] Heath GBS, Watt DJ, Waite PR, and Ormond JM. 1981. Observations on poultry slaughter. The Veterinary Record 108(5):97-9.
[104] Shane S. 2005. Future of gas stunning. WATT Poultry USA 6(4):16-23.
[105] Van der Sluis W. 2007. Gas stunning reduces rejects in spent hen processing. World Poultry 23(9):30-1.
[106] Webster AB. 2007. The commercial egg industry should consider controlled atmosphere stunning for spent hens. The Poultry Site, July. www.thepoultrysite.com/articles/864/the-commercial-egg-industry-should-consider-controlled-atmosphere-stunning-for-spent-hens. Accessed September 5, 2008.
[107] National Institute for Animal Agriculture. 2007. U.S. broiler health shows slight decline. Poultry Health Report, Fall/Winter, p. 2. www.animalagriculture.org/publications/poultry/2007PHR/Poultry Fall-Winter 2007.pdf. Accessed September 5, 2008.
[108] Bilgili SF. 1999. Recent advances in electrical stunning. Poultry Science 78(2):282-6.
[109] Gregory NG. 1986. The physiology of electrical stunning and slaughter. In: Humane Slaughter of Animals for Food Symposium (Hertfordshire, U.K.: Universities Federation for Animal Welfare, pp. 3-14).
[110] Raj ABM. 2003. A critical appraisal of electrical stunning in chickens. World's Poultry Science Journal 59(1):89-98.

[111] Raj ABM, O'Callaghan M, and Knowles TG. 2006. The effects of amount and frequency of alternating current used in water bath stunning and of slaughter methods on electroencephalograms in broilers. Animal Welfare 15(1):7-18.
[112] Gregory NG and Wotton SB. 1986. Effect of slaughter on the spontaneous and evoked activity of the brain. British Poultry Science 27:195-205.
[113] Raj ABM, O'Callaghan M, and Hughes SI. 2006. The effects of amount and frequency of pulsed direct current used in water bath stunning and of slaughter methods on spontaneous electroencephalograms in broilers. Animal Welfare 15(1):19-24.
[114] Raj ABM. 2004. Stunning and slaughter. In: Perry GC (ed.), Welfare of the Laying Hen (Wallingford, U.K.: CAB International).
[115] Gregory NG. 1986. The physiology of electrical stunning and slaughter. In: Humane Slaughter of Animals for Food Symposium (Hertfordshire, U.K.: Universities Federation for Animal Welfare, pp. 3-14).
[116] Raj ABM. 2004. Stunning and slaughter of poultry. In: Mead GC (ed.), Poultry Meat Processing and Quality (Cambridge, U.K.: Woodhead Publishing Ltd.).
[117] Heath GBS, Watt DJ, Waite PR, and Ormond JM. 1981. Observations on poultry slaughter. The Veterinary Record 108(5):97-9.
[118] Heath GBS, Watt DJ, Waite PR, and Meakins PA. 1983. Further observations on the slaughter of poultry. British Veterinary Journal 139(4):285-90.
[119] Raj ABM. 2004. Stunning and slaughter of poultry. In: Mead GC (ed.), Poultry Meat Processing and Quality (Cambridge, U.K.: Woodhead Publishing Ltd.).
[120] Shane S. 2005. Future of gas stunning. WATT Poultry USA 6(4):16-23.
[121] Food Safety and Inspection Service. 2005. Poultry Slaughter Inspection Training. Poultry postmortem inspection, p. 15. www.fsis.usda.gov/PDF/PSIT_PostMortem.pdf. Accessed September 5, 2008.
[122] U.S. Department of Agriculture National Agricultural Statistics Service. 2008. Poultry slaughter: 2007 annual summary. http://usda.mannlib.cornell.edu/usda/current/PoulSlauSu/PoulSlauSu-02-28-2008.pdf. Accessed September 5, 2008.
[123] Boyd F. 1994. Humane slaughter of poultry: the case against the use of electrical stunning devices. Journal of Agricultural & Environmental Ethics 7(2):221-36.
[124] Raj M. 1998. Welfare during stunning and slaughter of poultry. Poultry Science 77(12):1815-9.
[125] Raj M. 1998. Welfare during stunning and slaughter of poultry. Poultry Science 77(12):1815-9.
[126] Kotula AW, Drewniak EE, and Davis LL. 1957. Effect of carbon dioxide immobilization on the bleeding of chickens. Poultry Science 36(3):585-9.
[127] Duncan IJH. 1997. Killing methods for poultry: a report on the use of gas in the U.K. to render birds unconscious prior to slaughter (Guelph, Ontario: The Colonel K.L. Campbell Centre for the Study of Animal Welfare, University of Guelph).
[128] Webster AB and Fletcher DL. 2004. Assessment of the aversion of hens to different gas atmospheres using an approach-avoidance test. Applied Animal Behaviour Science 88(3-4):275-87.
[129] Raj ABM. 1996. Aversive reactions of turkeys to argon, carbon dioxide and a mixture of carbon dioxide and argon. The Veterinary Record 138(24):592-3.
[130] Raj ABM. 2004. Stunning and slaughter of poultry. In: Mead GC (ed.), Poultry Meat Processing and Quality (Cambridge, U.K.: Woodhead Publishing Ltd.).
[131] Raj M. 1998. Welfare during stunning and slaughter of poultry. Poultry Science 77(12):1815-9.
[132] Raj ABM. 2004. Stunning and slaughter. In: Perry GC (ed.), Welfare of the Laying Hen (Wallingford, U.K.: CAB International).
[133] Raj M. 1998. Welfare during stunning and slaughter of poultry. Poultry Science 77(12):1815-9.
[134] Raj ABM. 1996. Aversive reactions of turkeys to argon, carbon dioxide and a mixture of carbon dioxide and argon. The Veterinary Record 138(24):592-3.
[135] Webster AB and Fletcher DL. 2004. Assessment of the aversion of hens to different gas atmospheres using an approach-avoidance test. Applied Animal Behaviour Science 88(3-4):275-87.
[136] Personal correspondence between co-author Mohan Raj and Anglia Autoflow Ltd.

[137] Andrews E, Bennett BT, Clark JD, et al. 1993. Report of the AVMA Panel on Euthanasia. Journal of the American Veterinary Medical Association 202(2):229-49. www.nal.usda.gov/awic/pubs/noawicpubs/avmaeuth93.htm. Accessed September 5, 2008.
[138] Webster AB and Fletcher DL. 2004. Assessment of the aversion of hens to different gas atmospheres using an approach-avoidance test. Applied Animal Behaviour Science 88(3-4):275-87.
[139] McKeegan DEF, McIntyre J, Demmers TGM, Wathes CM, and Jones RB. 2006. Behavioural responses of broiler chickens during acute exposure to gaseous stimulation. Applied Animal Behaviour Science 99(3-4):271-86.
[140] McKeegan DEF, Abeyesinghe SM, McLeman MA, et al. 2007. Controlled atmosphere stunning of broiler chickens. II. Effects on behaviour, physiology and meat quality in a commercial processing plant. British Poultry Science 48(4):430-42.
[141] Abeyesinghe SM, McKeegan DEF, McLeman MA, et al. 2007. Controlled atmosphere stunning of broiler chickens. I. Effects on behaviour, physiology and meat quality in a pilot scale system at a processing plant. British Poultry Science 48(4):406-23.
[142] McKeegan DEF, Abeyesinghe SM, McLeman MA, et al. 2007. Controlled atmosphere stunning of broiler chickens. II. Effects on behaviour, physiology and meat quality in a commercial processing plant. British Poultry Science 48(4):430-42.
[143] McKeegan DEF, McIntyre JA, Demmers TGM, et al. 2007. Physiological and behavioural responses of broilers to controlled atmosphere stunning: implications for welfare. Animal Welfare 16(4):409-26.
[144] Sandilands V, Raj ABM, Baker L, and Sparks NHC. 2006. Aversion of chickens to various gases: methods for humane culling. In: Mendl M, Bradshaw JWS, Burman OHP, et al. (eds.), Proceedings of the 40th International Congress of the International Society for Applied Ethology (Bristol, U.K.: ISAE Scientific Committee, p. 64).
[145] Sandilands V, Raj ABM, Baker L, and Sparks NHC. 2008. Humane culling of poultry during a disease outbreak: aversion to various gas mixtures. British Poultry Abstracts 4(1):22-3.
[146] Raj ABM. 2004. Stunning and slaughter of poultry. In: Mead GC (ed.), Poultry Meat Processing and Quality (Cambridge, U.K.: Woodhead Publishing Ltd.).
[147] Gazdziak S. 2007. Kill floor improvements: automation on the poultry kill and eviscerating lines is increasing efficiency and product quality. The National Provisioner, December, pp. 66, 68.
[148] Raj ABM. 2004. Stunning and slaughter of poultry. In: Mead GC (ed.), Poultry Meat Processing and Quality (Cambridge, U.K.: Woodhead Publishing Ltd.).
[149] Gregory NG and Whittington PE. 1992. Inhalation of water during electrical stunning in chickens. Research in Veterinary Science 53(3):360-2.
[150] Raj ABM. 2004. Stunning and slaughter of poultry. In: Mead GC (ed.), Poultry Meat Processing and Quality (Cambridge, U.K.: Woodhead Publishing Ltd.).
[151] MBA Poultry. 2006. Smart Chicken. Pioneering controlled atmosphere stunning in the United States. www.smartchicken.com/fac.html. Accessed September 5, 2008.
[152] Kingsbury A. 2007. Controlled atmospheric stunning: ACA Co-operative installs North America's first system for broilers. Canadian Poultry Magazine, August, pp. 28-30. www.canadianpoultrymag.com/content/view/867/. Accessed September 5, 2008.
[153] European Food Safety Authority. 2004. Opinion of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of the main systems of stunning and killing the main commercial species of animals. The EFSA Journal 45:1-29.
[154] World Organisation for Animal Health (OIE). 2008. Terrestrial Animal Health Code 2007. Section 3.7.5. Guidelines for the slaughter of animals. www.oie.int/eng/normes/mcode/en_chapitre_3.7.5.htm. Accessed September 5, 2008.
[155] World Organisation for Animal Health (OIE). 2008. Terrestrial Animal Health Code 2007. Section 3.7.5. Guidelines for the slaughter of animals. www.oie.int/eng/normes/mcode/en_chapitre_3.7.5.htm. Accessed September 5, 2008.

The Humane Society of the United States is the nation's largest animal protection organization—backed by 10 million Americans, or one of every 30. For more than a half-century, The HSUS has been fighting for the protection of all animals through advocacy, education, and hands-on programs. Celebrating animals and confronting cruelty. On the Web at humanesociety.org.