Gary Smith and I originally wrote this paper in 1999. Since 1999, there have been many improvements in animal handling and stunning. Animal welfare audits by restaurant and supermarket companies have resulted in big improvements in many countries. Audits started by McDonald's Corporation and Wendy's International caused plant management to implement their own internal audits and do a better job training employees and operating equipment. Surveys done in both Europe and the U.S. that are outlined in this paper indicated that some plants had very poor animal welfare. More recent data in Grandin (2000) and data posted in the survey section of www.grandin.com shows that many plants have improved since this paper was written. Auditing of animal welfare in slaughter plants has greatly increased since 1999 in the U. S., Australia, New Zealand, and Europe. The USDA in the the U.S. has also increased enforcement of the Humane Slaughter Act. Animal welfare in slaughter plants in South America is also improving due to audits from restaurants and supermarkets.

Manteca (1998) says concern for animal welfare is a major consideration in meat production and is based upon the belief that animals can suffer. Welfare may be considered (Manteca, 1998) in terms of the subjective experiences of animals (measured using preference testing) or in terms of biological functioning (measured using reactions to stress including plasma levels of glucocorticoids, catecholamines, prolactin and endorphins as well as heart rate and brain levels of neurotransmitters). Meat consumers are increasingly demanding that animals be reared, handled, transported and slaughtered using humane practices (Appleby and Hughes, 1997). Public pressure for increased protection and welfare of animals comes primarily from people in largely urbanized populations, is inversely related to the proportion of a population that is engaged in agriculture and is increasing in importance throughout the world (Appleby et al., 1992). Concern about the welfare of animals is contingent on people believing that animals, if improperly cared for or mistreated, can experience pain and suffering (Dawkins, 1990). Research now clearly shows that mammals and birds feel pain and fear.

The most important factor determining whether a packing plant has good or bad animal welfare practices is the attitude of management personnel. Grandin (1998c) has said that, during her 25-year career, the plants that have good handling and stunning practices have a top manager who “cares” about animal welfare; as upper-management personnel change, handling and stunning
improve or decline, depending largely upon the attitude of the new person. Purnell (1998) quotes Temple Grandin as saying “The best facilities and the latest technology make handling cattle easier but they don’t make the manager; and until the owner or manager is convinced that proper handling practices pay off economically, it’s unlikely that employees will follow procedures day-in and day-out. The manager that is most effective in maintaining high humane standards is involved enough in day-to-day operations to know and care, but not so involved that he or she becomes numb and desensitized (Grandin, 1994).

McGlone (1997), Grandin (1987) offers the following tips for handling swine: (a) Pigs will follow other pigs, so it’s best to move small groups of pigs rather than single pigs. (b) Large groups (more than 15 pigs) are more difficult to direct and move than several small groups. (c) Plan ahead to allow appropriate time and set the route before you begin, making sure there is only one way for the pigs to go. (d) Move pigs in a slow, steady and calm manner. (e) Use paddles and sorting panels to move pigs rather than using electric prods. (e) Use the animal’s flight zone to your advantage; because pigs can see in a wide range on either side, solid walls keep the animal’s focus in front. (f) Pigs will explore as they go; they will investigate unique lighting, smells, surfaces, sounds and other animals. (g) On a day-to-day basis, touching pigs is a good idea but make sure each experience is positive. (h) Some genotypes of pigs tend to be more fearful of humans than others; so, genetics (selection for calm, easy-going types) is important. Grandin (1998e) said ultra lean hybrid pigs tend to display higher incidences of blood-splash and broken backs during slaughter and that those problems are especially evident in large, double-muscled pigs. Solving the problem will require changing genetics (Grandin, 1998e).

Grandin (1998d) believes that some cattle handling systems work like well-oiled machines, while others bog down with cattle that constantly balk and turn around. There are usually (Grandin, 1998d) three basic problems in crowd-pens and chutes: (a) Distractions, such as a chain hanging down in the chute entrance, that cause balking. (b) Poor handling methods, like overloading the crowd-pen with too many cattle. (c) Layout mistakes in the crowd-pen and chute.

When an animal welfare problem occurs in a plant, the cause of the problem must be determined. If the cause of the animal welfare problem is properly diagnosed, it will be easier to correct the problem. Critical to the process is identifying which of the following items is causing the problem: (1) Lack of supervision and training of employees. (2) Poor maintenance of stunning equipment, restraint systems, gates and other animal handling equipment (slick floors are a common maintenance problem). (3) Distractions that make animals balk and refuse to move (for example, inadequate lighting, air blowing toward approaching animals or animals being able to see people up ahead; Grandin, 1996a). (4) Condition of animals arriving at the plant. (It is difficult to humanely handle weak debilitated animals that are non-ambulatory. Pigs with an overly excitable temperament, that balk at minor things, create handling problems; these problems are often worse in very lean pigs. Producers should walk in their finishing pens and induce pigs to flow around them every day. This trains the pigs to quietly get up and move in the desired direction; only 10 or 15 seconds per pen per day, for the entire finishing period, is
required to accomplish such training.) (5) Design problems with equipment. (Before going to the expense of changing equipment, items 1, 2, 3 and 4, above should be ruled-out as causes of the problem). A common design problem, that can create problems with animal handling, is a beef stunning box that is too wide.

Facco Silveira et al. (1998) reported that preslaughter stunning should render animals insensible to pain and that welfare perspectives have also made it imperative to ensure that animals do not suffer needlessly during slaughter; stunning methods must provide assurance that adverse effects (blood-splash, fractures and PSE meat) are avoided. Shaw and Jones (1988) used Fourier techniques to evaluate pre-stun and post-stun electroencephalograms (EEG) of adult cattle stunned with electricity or by use of a captive-bolt device and concluded that such procedure can be used to provide objective evidence of changes in the EEG signals following stunning to assess the effectiveness and humaneness of various stunning procedures. Numerous scientific studies show that properly done captive bolt and electrical stunning induce instantaneous insensitivity (Gregory, 1998).

**COMPARISONS OF ELECTRICAL STUNNING AND CO2 STUNNING**

In the European Union, there is a legal requirement that all captive bolt and electrically stunned animals destined for meat consumption must be rendered insensible instantly and remain insensitive to pain until there is a complete loss of brain responsiveness due to exsanguination (Council Directive 93/119/C). Insensibility is not instantaneous with gas stunning. All animals stunned with gas must remain insensible until exsanguination (bleeding) has eliminated brain responsiveness. This is the main concern when the suitability of a stunning method is analyzed from an animal welfare point of view (Velarde et al., 1998). Internationally, the two most commonly used methods for commercial pre-slaughter stunning of pigs are electrical stunning and CO2 anesthetization. CO2 stunning is used more and more but electrical stunning is still widely used with the arguments for choice of method related to animal welfare and meat quality (Henckel, 1998).

**MEAT QUALITY AND STUNNING**

The physiological effect of the two most commonly used methods of pig stunning differs. CO2 anesthetization results in a lowering of the blood pH which leads to loss of consciousness (Eisele et al., 1967) and the electric current used in electrical stunning produces an epileptiform activity in the brain leading to unconsciousness without a simultaneous lowering of the blood pH (Hoenderken, 1978). Electrical stunning will, on the other hand, be followed by an acute fall of the muscle pH due to the powerful activation of the glycolysis in the muscles (Henckel, 1998). Individual differences, among animals, in the stress response are important in welfare issues; slaughter poses particular problems and neurophysiology has provided objective criteria to assess the effectiveness of electrical stunning (Monteca, 1998).
The current methods of stunning such as electroanaesthesia and CO2 exposure, are designed to induce physiological changes in the animal’s brain so as to render it insensitive before slaughter (Faucitana et al., 1998). From a meat quality standpoint, both electrical stunning and CO2 stunning affect the rate of postmortem muscle glycolysis in pigs due to increased muscle activity and elevated release of catecolamines into the blood (Troeger and Woltersdorf, 1990; Troeger, 1991). PSE incidence increases after use of electrical stunning (Van der Wal, 1978; Troeger and Woltersdorf, 1990) whereas CO2 stunning reduces incidence of PSE pork (Larsen, 1983).

Facco Silveira et al. (1998) compared unstunned/unrestrained slaughter to both electrical stunning and CO2 stunning of pigs and concluded that: (a) Any stress placed upon pigs immediately before slaughter should be avoided. (b) The relatively high glycolytic rate of unstunned/unrestrained animals highlights the need for care in handling swine in the period immediately prior to slaughter. (c) Muscle pH was higher and water-holding capacity was most desirable when pigs were CO2 stunned, intermediate when pigs were electrically stunned, and least desirable when pigs were unstunned/unrestrained. Henckel (1998) compared electrical stunning and CO2 stunning of market hogs and found that for pigs with similar genetic background (free from the Halothane gene) and with the same environmental exposure prior to stunning, electrical stunning resulted in twice the drip loss from the longissimus muscle with the same muscle pH and meat color.

EFFECT OF ABATTOIR MANAGEMENT ON STUNNING

Velarde et al. (1998) found a significant abattoir effect on all indicators of effectiveness of stunning, whereas the stunning method had a significative effect only on the percentages of animals: (a) showing no corneal reflex or (b) showing either the absence of corneal reflex or the absence of rhythmic breathing were absent (P<0.10). In Spanish plants, the proportion of animals showing absence of corneal reflex was lower on exiting the CO2 stunner than after electrical stunning (61.8 vs. 98.9%). For the combined onset of corneal reflex and rhythmic breathing, one abattoir had a lower index than others while one abattoir was intermediate and significantly lower than the remaining two plants equipped with the electrical stunning system. In well managed North American abattoirs using head to back cardiac arrest electric stunning less than 1 in 1,000 pigs exhibited a corneal reflex (Grandin, 1997b). Under commercial conditions, CO2 stunning was less effective in terms of the rapid onset of insensibility in pigs which may have been due to the stop/start manual nature of the system which can lead to a certain variability in the time of exposure to the gas of the pigs in the different positions in the well. Of the hoisted animals, 12.8% in one plant and 33.3% in another plant had signs of recovery from the stun (arched-back righting reflex caused by running the system beyond rated capacity, floppy head and rhythmic breathing) whereas the pigs stunned electrically did not show any signs of recovery on the bleeding rail (Velarde et al., 1998). Velarde et al. (1998) concluded that the administration of an electrical current with 220 V and 800 Hz spanning the brain, in combination with an electrical current with 110 V and 50 Hz passing through the heart, was more effective than the CO2 stunning system effectiveness, the exposure to the gas and the stun to stick interval must be considered carefully in order to prevent the animals from regaining sensitivity after stun. The differences in the efficiency of the two CO2 stunners evaluated.
underlines the importance of correct handling of the system (Velarde et al., 1998). The problems found by Velarde et al. (1998) have been corrected in North American plants. See the survey section of www.grandin.com.

Faucitana et al. (1998) surveyed four commercial pig abattoirs, two of which used the Midas Stunning System (chest belt with an automatically applied, head-only electrical stunner, followed by head-to-chest electrical stunner) and two of which used a Compact Carbon Dioxide Stunning Unit (filled with 83% CO2) and reported that the higher degree of muscle activity during the epileptic attack of electrically stunned pigs compared to gas-stunned pigs led to a higher incidence of PSE meat in their carcasses. The Faucitana et al. (1998) results agreed with the findings of Barton-Gade (1993) who observed an increased incidence (10 to 19%) of PSE in plants equipped with electrical stunning than in plants using CO2 stunning (PSE incidence of 2 to 6%).

ELECTRICAL STUNNING

Berghaus and Troeger (1998) reported that while most existing equipment for use in electrical stunning of pigs is based on the 50 Hz sinusoidal voltage available from the main power, producers of electrical stunning equipment now offer units with up to 800 Hz stunning frequencies. Use of the higher stunning frequencies for electrical stunning of pigs is purported to lessen problems with blood-splash and broken backs. The presence of an epileptic state is considered to be a guarantee of an effective electrical stun (Hoenderken, 1978, 1983; Simmons (1995) demonstrated that the minimum current required to induce epilepsy depends on the stunning frequency.

Velarde et al. (1998) reported that the electrical system is the most widely used stunning method in the European Union, and that it consists of passing electricity through the brain to produce instantaneous insensibility; stunning is achieved by inducing a tonic/clonic epileptic fit, before any pain stimulus associated with the application itself is detected and transmitted to the central nervous system (15 milliseconds). Velarde et al. (1998) said that due to its adverse effects on meat quality and on animal welfare (recovery of sensibility) in many Spanish abattoirs the traditional head-only electrical stunning has been replaced by the head-to-chest electrical stunner combined with the chest-belt restrainer (Midas system). The application of the cardiac arrest cycle has a major animal welfare advantage in that it promotes the start of death at the point of stun and relegates sticking to a method of removing blood from the carcass (Wotton and Gregory, 1986).

Velarde et al. (1998) reported that, in agreement with Wotton and Gregory (1986), the utilization of the head-to-chest device for pig stunning led to the instantaneous and irreversible onset of insensibility in 98.7% of the animals, although in some 16% of the cases studied it was observed that the electrical tongs were not exactly positioned between the eyes and ears on the pig’s head. It seems, therefore, that if a high voltage current is applied on the head, the accuracy of the electrode placement on the head is not so important (Velarde et al., 1998). Grandin 1997a,
1994 emphasizes the importance of never applying the electrodes to the animal’s neck. In most well managed North American plants, the stunning tongs are placed correctly on over 99% of the pigs. See the survey section on www.grandin.com. Grandin (2001) found that placing the tongs in the wrong location was a major cause of return to sensibility. An article in Pork ’98 (1998) quotes Nicola Simmons, a New Zealand animal scientist, as saying electrical stunning of swine has negative effects in the form of high amounts of carcass damage (broken bones and blood-splash) and negative meat-quality effects (decreased tenderness, increased drip loss and paler muscle color) but it is the most economical form of stunning and it is the most favorable from an animal welfare standpoint of all commercially available pig-stunning systems. To minimize the negative effects of electrical stunning on the incidence of PSE in pork, an automatic head-only and head-to-chest electrical stunner has been developed which induces a cardiac-arrest cycle and eventually produces a reduction of the clonic convulsions of the animal at sticking due to the inhibition of the spinal nerve function (Gilbert et al., 1984). The lower degree of muscle activity during the clonic phase would impede the onset of the PSE condition (Grandin, 1985).

Berghaus and Troeger (1998) evaluated animal welfare implications of higher frequency (500 or 800 Hz) electrical stunning in comparison to “normal” (50 Hz) stunning and concluded that: (a) All stunning frequencies tested (50, 500, 800 Hz) caused an effective stun (epileptic fit) within a minimum current flow time (1.3 ampere constant) of 0.3 seconds. (b) The minimum electrical charge (ampere x seconds) to induce epilepsy under laboratory conditions can be calculated within 0.4 Coulomb; this is less than 1/10 of the amount resulting after usual stunning operations (current flow time of 4 seconds). (Troeger and Woltersdorf, 1998, reported that a higher electrical charge during stunning causes deterioration in meat quality characteristics.) (c) The use of higher stunning frequencies did not result in a reduction of time of unconsciousness under laboratory conditions, as was described by Anil and McKinstry (1992). On the contrary, the duration of the tonic phase was longer with 800 Hz stunning frequency than with 50 Hz stunning and the recovery of breathing was delayed after 500 Hz stunning as compared with 50 Hz stunning. (d) All stunning frequencies tested were in conformance with animal welfare demands. The difference may be explained by the fact that Anil and McKinstry used very high frequencies of over 1,500 hz.

To insure that animals are instantly rendered insensible, electrical stunning must be applied correctly. Electrical stunning equipment must operate within electrical parameters which have been verified by scientific research to induce instantaneous insensibility (Grandin, 1997a). Scientific research has shown that an electrical stunner must have sufficient amperage to induce a grand mal seizure to insure that the animal will be made instantly insensible. Insufficient amperage can cause an animal to be paralyzed without losing sensibility. For market-weight pigs, a minimum of 1.25 amps is required (Hoenderken, 1983). For sheep, a minimum of 1.00 amp is required (Gregory and Wooton, 1984; Gilbert et al., 1991). These amperages must be maintained for one second, during stunning, to induce instant insensibility. The Council of Europe (1991) recommends use of the afore-mentioned minimum amperages during electrical stunning for pigs and sheep.
There must be sufficient voltage, during electrical stunning, to deliver the recommended minimum amperage; 250 volts is the recommended minimum voltage for pigs to insure insensibility (Troeger and Woltersdorf, 1989). Research has also shown that too high an electrical frequency will result in failure to induce insensibility. Warrington (1974) found that insensibility was most effectively induced at frequencies of 50 cycles. Frequencies at 2000 to 3000 hz failed to induce instant insensibility and may cause pain (Croft, 1952; Van der Wal, 1978). However, in pigs weighing under 200 lbs (80 kg), Anil and McKinstry (1992) found that high frequency, 1592 hz sinewave or 1642 hz square-wave, head-only for stunning at 800 ma (0.80 amp) would induce seizure activity and insensibility in small pigs. One disadvantage of stunning under the aforementioned conditions, is that the pigs regain sensibility more quickly than do pigs stunned using frequencies of 50 to 60 cycles. The pigs in the latter experiment (Anil and McKinstry, 1992) weighed one-third less than comparable U.S. market pigs and this probably explains why the lower amperages were effective.

Some plants stun animals using amperages below those recommended as the minimum by the Council of Europe (1991) in an attempt to reduce blood spots in the meat. Stunning market-weight pigs with less than 1.25 amps should not be permitted (Hoenderken, 1983; Grandin, 1994a) unless use of different electrical parameters are verified by either electrical or neurotransmitter recordings from the brain. Grandin (1997a) believes that, because only a 1 second application at 1.25 amps is required to induce instant insensibility in market-weight pigs, plants should be permitted to use circuits which lower the amperage setting after an initial, 1 second stun, at 1.25 amps for pigs or at 1 amp for sheep. Plants should also be encouraged to use electronic-constant amperage circuits which prevent amperage spiking (Grandin, 1997a, 1985). Both practical experience and research have shown that the aforementioned types of circuits greatly reduce petechial hemorrhages (blood spots) in carcass muscles (Grandin, 1985; Blackmore and Peterson, 1981).

Because U.S. market pigs are slaughtered at heavier weights than are European pigs, an electrical stunner must deliver the minimum amperage recommended by the Council of Europe (1991) to insure instantaneous insensibility. Grandin (1997a) believes that high-frequency stunning (at frequencies higher than those tested by Anil and McKinstry, 1992) should not be permitted in the U.S. until research is conducted to prove that such stunning is capable of inducing an instantaneous grand mal seizure in heavier, U.S. market-weight pigs. In the Anil and McKinstry (1992) experiment, the pigs were stunned with a head-only applicator. High frequency stunning has never been verified to induce instant insensibility when applied with a head-to-body, cardiac arrest, stunning electrode (the type of electrode used in almost all large U. S. pork slaughter plants). In the Velard et al., 1998 study the pigs were stunned with a high frequency 800 hz current through the brain and then a second 50 hz current was passed through the heart to induce cardiac arrest. The high frequency 800 hz current was effective with this “split stun procedure.” In most U.S. plants, a single current is passed from head to body, and frequencies of over 50 to 60 hz are still not verified when used with an electrode where a single current is passed from the head to the body. Grandin (1997a) recommends that when a single current is passed from head to body the first 1 second should be a minimum of 1.25 amps at 50 to 60 hz. Therefore, Grandin (1998c) recommends that higher frequencies should only be used
when they are passed through two electrodes on the head. Research is still needed to verify insensibility when frequencies over 60 hz are passed from head to body.

Electrical stunning of cattle requires a two-phase stun whereas pigs and sheep are electrically stunned by use of a single-phase application of current. Due to the large size of cattle, a current must first be applied across the head to render the animal insensible before a second current is applied from the head to body to induce cardiac arrest (Gregory, 1993). A single 400 volt, 1.5 amp current passed from the neck to the brisket failed to induce epileptic form changes in the brain (Cook et al., 1991). To insure that the electrodes remain in firm contact with the bovine animal’s head for the duration of the stun, the animal’s head must be restrained in a mechanical apparatus. The Council of Europe (1991) requires a minimum of 2.5 amps applied across the head to induce immediate epileptiform activity in the EEG of large cattle. A frequency of 50 or 60 cycles should be used unless higher frequencies are verified by either electrical or neurotransmitter measurements taken from the brain. More recent research has shown that 1.2 amps for 2 seconds is effective (Wotton and Gregory, 2000). For more information on electric stunning of cattle, see the humane slaughter section of www.grandin.com.

For all species, electrodes must be cleaned frequently to insure that a good electrical connection occurs between stunner and animal. The minimum cleaning schedule is once a day; and, for safety, the electrode wand must be disconnected from the power supply before cleaning. Adequate electrical parameters for cardiac arrest stunning cannot be verified by clinical signs, because cardiac arrest masks the clinical signs of a seizure. Measurement of brain function is required to verify any new electrical parameters which may be used in the future (Grandin, 1997a).

If head-only stunning is used, the tongs must be placed so that the current passes through the brain (Croft, 1952; Warrington, 1974). Tongs may be placed on both sides of the head or one tong can be placed on the top and the other tong placed on the bottom of the head. Another scientifically verified location for head-only stunning is with one electrode placed under the jaw, and the other electrode placed on side of the neck right behind the ears. For cardiac-arrest stunning of pigs and sheep, one electrode must be placed on the head and the other electrode may be placed at any location on the body to induce cardiac arrest. The head electrode may be placed on the forehead, side of the head, top of the head, under the jaw, or in the hollow behind the ear, but must never be placed on the neck because this would cause the current to bypass the brain. Electrodes must not be applied to sensitive areas such as inside the ear, in the eye or in the rectum.

When head-only reversible stunning is used, the animal must be bled promptly to prevent return to sensibility. Hoenderken (1983) states that pigs must be bled within 30 seconds, whereas Blackmore and Newhook (1981) recommend that they be bled within 15 seconds, to insure that they remain insensible throughout bleed-out. Grandin (1994) observed that in some small locker plants which used a slow hoist for elevating electrically stunned pigs, proper bleed-out was not accomplished within 30 seconds.
CAPTIVE-BOLT STUNNING

The most common cause of low efficacy scores for use of captive-bolt stunning in the USDA Survey was poor maintenance of the captive-bolt stunner (Grandin, 1998b). Captive-bolt stunners must be cleaned and serviced, following the manufacturer’s recommendations, to maintain maximum hitting power and to prevent misfiring or partial-firing. High bolt velocity causes a concussion that induces instantaneous insensibility (Daly and Whittington, 1989; Blackmore, 1985). Each plant should develop a system of verified maintenance for captive-bolt stunners. Pneumatic-powered captive-bolt stunners must be operated at the air pressure recommended by the manufacturer. A major cause of failure to render animals insensible with one captive-bolt shot is poor ergonomic design (some pneumatic stunners are so bulky it is very difficult to achieve correct stunner placement on the animal’s forehead). Ergonomics can sometimes be improved by use of a handle extension and improved balancers.

Aversive methods of restraint which cause 3% or more of the cattle or pigs to vocalize must not be used as a substitute for improvements in ergonomics of captive-bolt stunners. Electrical immobilization must never be used as a method for restraining sensible animals prior to or during stunning. Several scientific studies have shown that electrical immobilization is highly aversive (Lambooy, 1985; Pascoe, 1986; Grandin et al., 1986; Rushen, 1986). Assessment of animal discomfort by counting vocalizations is impossible to achieve in electrically immobilized animals because paralysis prevents vocalization. Electrical immobilization must not be confused with electrical stunning. Properly done, electrical stunning passes a high amperage current through the brain and induces instantaneous insensibility. Electrical immobilization holds a sensible animal still, by paralyzing its muscles, and does not induce epileptiform changes in the EEG (Lambooy, 1985).

A third cause of missed captive-bolt stunner shots is an overloaded or fatigued operator. Assessment of stunning efficacy at the end of the shift will pinpoint this problem. In some large plants, prevention of the overloading/fatigue problem may require employment of two captive-bolt stunner operators or frequent rotation of cross-trained operators.

Research has shown that, for cattle, the most effective position for captive-bolt placement, to induce instantaneous insensibility, is in the middle of the forehead (Daly and Whittington, 1989). The hollow behind the poll should be avoided as a site for captive-bolt stunning except in large Bos indicus cattle which have a bony ridge in the forehead which makes captive-bolt stunning more difficult.

Observations of cattle stunning indicate that, under field conditions, penetrating captive-bolt stunners are more effective than non-penetrating captive-bolt stunners that have a mushroom-type head; observations in many plants indicate that there is less margin for error with non-penetrating captive-bolt stunners and the shot must be exactly on target to render the animal instantly insensible.
The use of a mechanical head restraint will improve the accuracy of captive-bolt stunning, but it can increase stress if it is improperly used (Ewbank and Parker, 1992). To minimize stress, the animal should be stunned within five seconds after its head is restrained. If more than 3% of the cattle vocalize (moo or bellow), the head restraint device will have to be modified to reduce stress. Animals should enter the head restraint easily, with a minimum of prodding.

**CARBON DIOXIDE STUNNING**

There has been controversy about the humaneness of carbon dioxide (CO2) stunning. Velarde et al. (1998) reported that, as in other countries, the use of CO2 stunning has recently increased in popularity in the European Union but its acceptability on welfare grounds has been questioned by several researchers. Gregory et al. (1987) examined the effectiveness of a compact stunner and suggested that insensibility is not instantaneous and narcosis began 30 to 39 seconds after the start of immersion procedure. Additionally, the exposure to the gas stimulates breathing frequency and may lead to respiratory distress (Raj and Gregory, 1995). On the other hand, from the study of the changes occurring in the EEG patterns of pigs, Forslid (1987) observed that pigs reach insensibility before the onset of the violent motor activity. Some people who are interested in animal welfare claim that CO2 stunning is extremely aversive to pigs while other people claim it is humane. Both practical experience and scientific studies indicate that genetic factors play a large role in determining the aversiveness of CO2 gas to pigs. For some genetic types of pigs, use of CO2 stunning is probably very humane and for other genetic types of pigs it may be very stressful.

Ring (1988) concluded that because pigs stunned with N2 in his study, in spite of lower PaO2 than the CO2-stunned pigs, did not show any signs of restlessness, choking attacks, collapsing or flight reflexes for two minutes, stunning with CO2 cannot be considered to be caused by hypoxia. Furthermore, Ring (1988) observed that, during the time before the stage of analgesia was experienced, the pigs were fully conscious; so, during this stage, unpleasant feelings cannot be excluded, but obvious signs of unpleasant feelings were not noticed. After the stage of excitation, the animals passed the stage of asphyxia when they were exsanguinated. Barfod and Madsen (1988) concluded that the loss of consciousness during CO2 anesthetization is rapid and is similar to other forms of narcosis and, therefore, it appears to be an acceptable method for pre-slaughter stunning. Forslid (1988) reported that determinations of plasma cortisol, adrenalin and noradrenalin did not provide any direct evidence that the inhalation of CO2 imposed any emotional strain in addition to that induced by the mere transport of the swine to the intermediate pre-exposure situation.

Dutch research indicated that the excitation phase which occurs during CO2 stunning starts prior to the onset of unconsciousness (Hoenderken et al., 1983); this study raised the question of potential distress in pigs during the induction of CO2 anesthesia. More recently, research by Forslid (1987) indicated that unconsciousness occurred prior to the onset of the excitation phase, therefore, CO2 stunning is definitely humane. All of the research conducted by Anders Forslid at the Swedish Meat Research Institute has been on Yorkshire pigs (Forslid, 1991). In Yorkshire
X Landrace crossbred pigs, exposure to CO2 was less aversive than were electrical shocks (Jongman et al., 1998). Aversion was measured by determining the time required to enter and re-enter a CO2 machine after being exposed to the gas or to an electrical shock. Other studies have shown that there is large variation among pigs with regard to their reaction to CO2 (Dodman, 1977; Grandin, 1988a). Grandin (1988a) observed, in a commercial slaughter plant in the U.S., that white crossbred pigs (with Yorkshire breedtype characteristics) had a much milder reaction to CO2 than black, white-striped crossbred pigs (with Hampshire breedtype characteristics).

Grandin (1988a) concluded that the effect of genetic stress susceptibility on reaction to CO2 needs to be studied because, possibly, CO2 may be acceptable from an animal welfare standpoint for some breeds or genetic lines within a breed and not acceptable for other breeds or genetic lines within a breed. Excitement and rough handling prior to entry into the Compact plant may also affect the animal’s reaction; so, there is a possibility that rough handling may have a large effect on pig reaction in one breed and little effect on pig reaction in another breed or genetic line within a breed (Grandin, 1998a).

Many of the Hampshire-type pigs, when stunned in a Wernberg Compact plant, started to react in the first few seconds after they contacted the gas. Hampshire-type pigs rode quietly in the gondola until they contacted the gas; they then attempted to rear up to avoid the gas while they were fully conscious (Grandin, 1988a). Grandin (1998c) observed that Danish pigs (which have a very low incidence of the Halothane gene) remained calm when they breathed CO2, but that Irish pigs (which have a high incidence of the Halothane gene) became highly agitated within seconds after sniffing the gas.

Experiments with Pietrain X German Landrace pigs indicated that Halothane-positive pigs had a more vigorous reaction to CO2 than Halothane-negative pigs (Troeger and Woltersdorf, 1991). These pigs had little or no reaction during initial contact with the gas; the reaction started about 20 seconds after the animals contacted the gas. Seventy percent of the Halothane-positive pigs had strong motoric reactions while only 29% of the Halothane-negative pigs reacted in this manner. Troeger and Woltersdorf (1991) expressed concern that reactions in Halothane-positive animals may possibly be of animal welfare concern but concluded that the use of high CO2 concentrations (80% or greater) reduced the incidence of vigorous reaction.

An earlier German study with pigs of unspecified genetics indicated that the animals were anesthetized before the excitation phase (Ring, 1988). It is likely that some Halothane-positive pigs were tested in the Ring (1988) investigation but further studies with both Halothane-positive and Halothane-negative Hampshire pigs are still needed. The effect of the Napole gene in the Hampshire breed also needs to be researched because many of the bad reactors in the Ring (1988) study had Hampshire coloration (Grandin, 1998a).

Human beings also vary in their reaction to CO2. People who have panic attacks which have a strong genetic basis will react very badly to CO2; the gas may induce panic attacks in these people (Griez, 1990; Bellodi et al., 1998). Lambooy (1990) reported that Neville Gregory from
the Meat Research Institute in England reviewed a number of studies that indicated that most people find the smell of CO2 gas to be pungent when it is breathed at a concentration of 50% (Lambooy, 1990).

In conclusion, CO2 stunning is probably very humane for use with certain genetic types of pigs and stressful for pigs of other genetic types. The use of a mixture of CO2 and argon gas may create an improved gas stunning system for poultry (Raj and Gregory, 1994). It is possible that a combination of CO2 and argon might make CO2 stunning less stressful for genetic types of pigs which react badly to CO2. Any research studies conducted to determine animal welfare aspects of gas stunning should use populations of pigs that include those that are both positive and negative for the Halothane gene and for the Napole gene.

ASSESSING INSENSIBILITY

Blackmore (1988) concluded that reflexes used to judge the depth of chemical general anesthetics are inappropriate to assess the state of sensibility of an animal during slaughter; thus, it is impossible to assess whether or not a slaughter process is humane by examination of individual animals at the abattoir. He believes, though, that sufficient information is now available to be able to construct specifications of a slaughter process which can be considered, with a high degree of confidence, to be humane (Blackmore, 1988). However, if an animal shows any signs of return to sensibility this is an indication of an obvious problem that must be corrected.

To assess insensibility in a meat plant one should look at the stunned animal’s head and ignore the reflexes occurring in the body. Reflexive movements and kicking will occur in insensible animals that have been properly stunned with electricity or a captive-bolt stunner. The mistake many people make is to look at leg kicking. Random limb movement can create a safety hazard when large cattle kick, and, this activity can occur in an unconscious animal.

When cattle or sheep are shot with a captive bolt, the animal should instantly drop to the floor if it is stunned in a box. In a conveyor restrainer, the head should drop down. It is normal for the head to go into a spasm for a few seconds before it drops. Insensibility in cattle can be evaluated immediately after the head spasm. In electrically stunned cattle, sheep or pigs, stunning induces a grand mal seizure which causes instant unconsciousness. This seizure causes rigid spasms which last for at least 30 seconds; these spasms can mask signs of insensibility. Under commercial conditions, the animal should not be evaluated for insensibility until 30 seconds after electric stunning. For more information on solving return to sensibility problems, refer to Grandin (2001) or the humane slaughter section of www.grandin.com.

At no time, either during or after stunning should the animal vocalize (squeal, moo or bellow). Vocalization is a sign that a sensible animal may be feeling pain. It is easy to evaluate insensibility after an animal is hanging vertically on the bleed rail; it should hang straight down and have a straight back, and the head should be limp and floppy (Grandin, 1994, 1997a). If the
stunned animal has kicking reflexes, the head should flop like a limp rag. If the animal makes any attempt to raise its head, it may still be sensible. An animal showing a righting reflex must be immediately re-stunned. There should also be no rhythmic breathing and no eye reflexes in response to touch. Blinking is another sign of an animal that has not been properly stunned and thus may still be sensible. Gasping is permissible; it is a sign of a dying brain (Gregory, 1994). If the tongue is hanging straight down and is limp and floppy, the animal is definitely stunned; if the tongue is curled, this is a sign of possible sensibility.

INSENSIBILITY IN POULTRY AND GAS-STUNNED ANIMALS

Do these same principles for determining insensibility apply to poultry or animals stunned by use of gas? The answer is definitely “yes.” The principles of determining insensibility are the same in all animals and birds. The heads of chickens or turkeys that have been stunned with electricity or gas should hang straight down after stunning. Birds which have not been properly stunned will show a strong righting reflex and raise their heads. Both mammals and birds which have been stunned with CO2 should be limp and floppy. Gas-stunned mammals and birds should not have reflexive movements and should not display kicking actions. The entire body and head should be flaccid and floppy. Any animal which shows eye reflexes or a righting reflex is not properly stunned.

RITUAL SLAUGHTER

Ritual slaughter is performed according to the dietary codes of Jews or Muslims. Cattle, sheep or goats are exsanguinated by a throat cut without first being rendered unconscious by pre-slaughter stunning. Ritual slaughter is exempt from the Humane Methods of Slaughter Act of 1978 in order to protect religious freedom in the U.S.; in Europe and Canada, however, ritual slaughter is covered by humane slaughter regulations. Because ritual slaughter is exempt in the U.S., some plants use cruel methods of restraint, such as suspending a conscious animal by a chain wrapped around one hind-limb. In more progressive plants, the animal is placed in a restrainer that holds it in a comfortable, upright position.

The latest guidelines for ritual slaughter, published by the American Meat Institute (Grandin, 1997a), strongly recommend the use of upright restraint devices. Most large cattle slaughter plants are using more comfortable methods of restraint, but there are still some plant managers who have no regard for animal welfare. They persist in hanging large cattle and veal calves upside down by one hind-leg. There is no religious justification for use of this cruel method of restraint. The plants that suspend cattle/calves by one hind-leg do so in order to avoid paying the cost of installing a humane restraint device. Humane restraint devices can often pay for themselves by improving employee safety (Grandin, 1995, 1991a).

When ritual slaughter is being evaluated from an animal welfare standpoint, the variable of restraint method must be separated from the act of throat cutting without prior stunning.
Distressful restraint methods mask the animals’ reactions to its throat being cut. Four state-of-the-art restraint devices have been designed, built and operated that hold cattle and calves in a comfortable upright position during kosher (Jewish) slaughter (Grandin, 1994; Grandin and Regenstein, 1994). To determine whether cattle feel the act of having their throat cut, Grandin (1994), at one plant, deliberately applied the head restrainer so lightly that the animals could pull their heads out; none of the 10 cattle moved or attempted to pull their heads out. Observations of hundreds of cattle and calves during kosher slaughter indicated that there was a slight quiver when the knife first contacted the throat (Grandin, 1994). Invasion of the cattle’s flight zone by touching its head caused a bigger reaction (Grandin, 1994, 1993b) than did the act of having its throat cut. The animal’s head must be restrained in such a manner that the incision does not close back over the knife. Cattle and sheep will struggle violently if the edges of the incision touch during the cut (Grandin, 1994).

The design of the knife and the cutting technique are critical for preventing the animal from reacting to an incision of its throat. In kosher slaughter, a straight, razor-sharp knife that is twice the width of the throat is required, and the cut must be made in a single continuous motion. For halal (Muslim) slaughter, there is no knife-design requirement. Halal slaughter performed with short knives and multiple hacking cuts results in vigorous reactions of cattle being treated in this manner. Fortunately, many Muslim religious authorities accept preslaughter stunning. Muslims should be encouraged to stun the cattle or to use long, straight, razor-sharp knives that are similar to the knives used for kosher slaughter.

Investigators agree that throat-cutting without stunning does not induce instantaneous unconsciousness. In some cattle, consciousness is prolonged for over 60 seconds (Blackmore, 1984; Daly et al., 1988). Grandin (1994) observed that near-immediate collapse can be induced in over 95% of cattle if the ritual slaughterer makes a rapid, deep cut close to the jawbone. Further observations indicated that calm cows and bulls lose sensibility and collapse more quickly than do cattle with visible signs of agitation (Grandin, 1994). Cattle that fight restraint are more likely to have prolonged sensibility; gentle operation of restraint devices facilities rapid loss of sensibility.

To provide the best possible animal welfare, restraint devices must be operated correctly. The most common problems in restraining animals involve applying excessive pressure to the body. If more than 5% of the cattle vocalize or struggle in the restraint device, it is either poorly designed or it is operated too roughly. A survey done in plants performing kosher slaughter in an upright restraint system indicated that under 5% of the cattle vocalized when the system was operated correctly (Grandin, 1997b). Dunn (1990) found that significantly more cattle vocalized when they were inverted onto their backs for ritual slaughter as compared to the number of cattle that vocalized when they were held in a restrainer that kept them in an upright position. Higher cortisol levels were also correlated with higher rates of vocalization (Dunn, 1990). Plants that shackle and hoist large cattle often have loud bellowing by more than 50% of the animals treated in that manner. In some cases, those vocalizations can be heard outside the building. Instructions for proper operation and design of comfortable upright restraint devices can be found on the internet at www.grandin.com and in papers by Grandin (1991b, 1992, 1993b, 1994,
1995). The use of comfortable restraining equipment complies with the religious principles of both halal and kosher slaughter. Kosher and halal slaughter were originally developed to spare the animal pain (Grandin and Regenstein, 1994).

**OBJECTIVE SCORING OF ANIMAL WELFARE**

The American Meat Institute Guidelines (Grandin, 1997a) outline objective scoring methods which can be used to assess animal welfare. The advantage of objective scoring is that different people will be able to provide comparable assessments of animal welfare (Grandin, 1998b). Those guidelines are a supplement to the 1991a Recommended Animal Handling Guideline for Meat Packers; the main emphasis of such guidelines is with regard to use of animal-welfare performance standards which can be objectively scored as an alternative to specifying equipment design or specific practices. Scoring procedures for assessing animal welfare, and recommendations which will help improve animal welfare are described in the Guidelines. The recommended scoring procedures are simple enough to be conducted easily under commercial conditions, and they should be conducted a minimum of once a week. Scoring should be done at both the beginning and the end of a shift to determine the effect of employee fatigue. If a score falls below the acceptable range specified in the Guidelines, plant management personnel should take steps to correct the problem. The results of the Survey of Stunning and Handling in Federally Inspected Beef, Pork, Veal and Sheep Slaughter Plants (sponsored by USDA’s Animal and Plant Health Inspection Service) indicated that the recommended minimum acceptable levels specified in this guide can be achieved easily and at a minimal of expense (Grandin, 1998b). Objective scoring should be done in those areas of the plant that are critical control points for good animal welfare. The minimum acceptable percentage scores used in the survey (Grandin, 1997a, 1997b) were determined by the survey’s author based on more than 20 years of practical experience in over 100 different slaughter plants. In conducting the survey, Grandin (1998b) considered the following: (1) Percentage of pigs or sheep on which the electrical stunner was placed in the wrong position. (2) Percentage of cattle that had to be shot more than once with the captive-bolt stunner. (3) Percentage of sensible and partially sensible animals on the bleed rail. (4) Percentage of animals falling down or slipping. (5) Percentage of cattle vocalizing in the stunning chute area (the stunning chute area includes the stunning box, restrainer, lead-up chute and crowd pen). (6) Percentage of pigs vocalizing in the stunning pen or on the restrainer conveyor. (7) Percentage of animals subjected to an electric prod. (8) Percentage of non-ambulatory animals and procedures used to move such animals to the stunning/sticking area (scoring procedures need to be developed at this critical control point).

- (I) Electrical Stunning And Electrode Placement Efficacy Criteria—(Score a minimum of 100 pigs or sheep in large plants). (a) Excellent. 99.5 to 100% correct placement of stunning wand or tongs. (b) Acceptable. 99.4 to 99% correct placement of stunning wand or tongs. (c) Not Acceptable. 98% to 95% correct placement of stunning wand or tongs; or, 4% or more of the pigs vocalizing due to energizing the electrodes before they are firmly positioned. (d) Serious Problem. Less than 95% correct placement of stunning wand or tongs; or, more than 4% vocalizing in response to improper electrode placement.
- (II) Captive-Bolt Stunning Efficacy Criteria—(Score a minimum of 100 animals in large plants). (a) Excellent. 99 to 100% instantly rendered insensible with one shot. (b) Acceptable. 95 to 98% instantly rendered insensible with one shot. (c) Not Acceptable. 90 to 94% instantly rendered insensible with one shot. (d) Serious Problem. Less than 90% instantly rendered insensible with one shot. If one-shot efficacy falls below 95%, immediate action must be taken to improve the percentage. If the first shot fails to induce instantaneous insensibility, the animal must be immediately re-stunned.

- (III) Considerations For Penetrating Captive-Bolt Stunning, Bleed-Out Interval—Does not have to be measured for animal welfare evaluations unless a non-penetrating captive-bolt is used. Additional study is needed to determine the recommended interval for time to render the animal insensible for non-penetrating captive-bolt stunning. All of the plants surveyed by Grandin (1998b) used penetrating captive-bolt stunners.

- (IV) Considerations For Electrical Stunning Bleeding Interval And Cardiac Arrest—Bleeding should occur within 60 seconds. All of the large plants surveyed by Grandin (1998b) were achieving cardiac arrest in less than 60 seconds.

- (V) Considerations For Head-Only, Reversible Electrical Stunning. Fifteen seconds is strongly recommended (Blackmore and Newhook, 1981) and 30 seconds is the maximum recommended (Hoenderken, 1983) to maintain insensibility. Scientific research clearly shows that pigs will start returning to sensibility after 30 seconds when stunned by use of the head-only reversible electrical stunning procedure.

- (VI) Bleeding Rail Insensibility Efficacy Criteria—(Score a minimum of 100 animals in large plants). (a) Excellent. Sensible cattle occurring at less than 1 per 1,000; sensible pigs occurring at less than 1 per 2,000. (b) Acceptable. Sensible cattle occurring at less than 1 per 500; sensible pigs occurring at less than 1 per 1,000. Animals showing any sign of return to sensibility MUST be immediately restunned BEFORE any other slaughter procedures. Procedures such as skinning, sicaulding, leg removal or other slaughter procedures MUST NEVER be performed on an animal that shows any sign of return to sensibility.

- (VII) Considerations For Slipping And Falling—Good animal welfare and quiet calm handling is impossible if animals slip or fall on the floor. All areas where animals walk should provide non-slip footing. Animals should be observed during all phases of handling and, if slipping or falling is observed, steps should be taken to correct it. Slipping on scales, unloading ramps and stunning boxes can often be corrected by installing a grating built from steel bars. A concrete-grooving machine can be used to roughen an existing floor. Since results of the plant survey for USDA (Grandin, 1998b) indicated that the greatest problems with slipping and falling were in the stunning chute area, scoring for that characteristic should be done there.
(VIII) Slipping And Falling In The Stunning Chute-Area Efficacy Criteria (All Species)
—(Score a minimum of 50 animals in large plants). The stunning chute area includes restrainer entrance, stunning box, lead-up chute and crowd pen. Scores assigned should consist of (a) Excellent. No slipping or falling. (b) Acceptable. Slipping of less than 3% of the animals. (c) Not Acceptable. 1% of the animals falling down (body touches floor). (d) Serious Problem. 5% falling down or 15% or more slipping.

(IX) Considerations For Vocalization Scoring Of Cattle—Vocalization (moos or bellows) is an indicator of cattle discomfort. Dunn (1990) reported that significantly more cattle vocalized when they were held in a restraint device that inverted them on their backs than when cattle were subjected to upright restraint. Research by Bridgett Voisinet at Colorado State University demonstrated that the number of times that cattle vocalize during a stressful husbandry procedure is related to cortisol (stress hormone) levels (Voisinet et al., ). Vocalization is correlated with physiological measures of stress in both cattle and pigs (Dunn, 1990; Warris et al., 1994).

Results of the plant survey for USDA indicated that the percentage of cattle which vocalized in the stunning chute area ranged from 3% or less of the cattle in the three best plants, to 12 to 32% in the two worst plants (Grandin, 1997b, 1998a). Cattle vocalizations in the stunning chute area were caused by use of an electric prod, slipping in the stunning box, missing with captive-bolt stunners or excessive pressure applied by a restraint device. USDA survey results (Grandin, 1997b, 1998b) showed that plants with a high percentage of vocalizing cattle could easily reduce this percentage; the average vocalization percentage in the two plants with the roughest handling was reduced from 22% of the cattle to 4.5% of the cattle by reducing electric prod usage.

Results of the plant survey clearly demonstrated (Grandin, 1998a) that cattle seldom vocalize during handling or stunning unless an easily observed, aversive event occurred. A total of 1,125 cattle were scored for vocalization (Grandin, 1998a) and 112 of those animals vocalized; only two animals vocalized which were not responding to an aversive event such as electric prodding, slipping, falling, missed stuns, or excessive pressure from a restraint device. Other aversive events which can cause vocalization are hitting cattle with gates or pinching an animal in a restraint device which indicates that vocalization is an indicator of discomfort.

(X) Vocalization Scoring Of Cattle In The Crowd Pen, Lead-Up Chute, Stunning Box Or Restraining Device Efficacy Criteria—(Score a minimum of 100 animals in large plants). (a) Excellent. 0.5% or less of the cattle vocalizing. (b) Acceptable. 3% or less of the cattle vocalizing. (c) Not Acceptable. 4% to 10% of cattle vocalizing. (d) Serious Problem. Over 10% of the cattle vocalizing.

When vocalization is being evaluated, cattle from more than one feedlot or ranch should
be observed. To make scoring simple, each animal should be classified as either a vocalizer or a non-vocalizer. Cattle vocalizations should be tabulated during handling in the crowd pen, lead-up chute, restrainer or stunning box. Vocalizations occurring in the yards should not be tabulated because cattle standing quietly in the yards will often vocalize to each other. In one plant (Grandin (1997b) observed that hungry Holstein-Friesian cattle vocalized and turned to face a man bedding a pen with sawdust; it appeared that they perceived the sawdust as feed.

Observations at one of the sheep slaughter plants during conduction of the survey indicated that vocalization during handling is absolutely useless as a measure of handling problems in sheep. Sheep walking quietly up the stunning chute often vocalized to each other while sheep which balked, and had to be pushed by a person, never vocalized (Grandin, 1997b). There is a species difference between cattle and sheep with respect to the circumstances in which they vocalize.

- (XI) Considerations For Vocalization Scoring Of Pigs—Research conducted in commercial pork slaughter plants indicated that the intensity with which pigs squealed (measured with a sound meter) in the stunning chute area was correlated with physiological measures of stress and with poorer meat quality (Warriss et al., 1994). White et al. (1995) also found that the intensity of pig squeals is correlated with pig discomfort.

Because it is impossible to count individual pig squeals when a group of pigs is being handled, vocalization scoring of individual pigs can only be conducted in the restrainer. Results of the survey (Grandin, 1997b, 1998b) indicated that there were two major causes of pig vocalizations: (a) misapplied electric stuns, and (b) pinching in the restrainer. Survey results further indicated that vocalization in the restrainer ranged from 0% to 14%, with 72% (8 of the 11 plants) having no pigs squealing due to misapplied electric stuns; in two of the plants 2 to 4% of the pigs squealed during stunning (Grandin, 1997b). The use of sound-level meters should be investigated as a means for monitoring pig vocalizations during handling.

- (XII) Vocalization Scoring Of Pigs In The Restrainer Or During Stunning—(Scores minimum of 100 pigs in large plants). (a) Excellent. 0% or less of the pigs vocalizing due to use of the restrainer; no vocalizing due to a misapplied stunning device. (b) Not Acceptable. 2% or more of pigs vocalizing in the restrainer for any reason. (c) Serious Problem. 5% or more of the pigs vocalizing in the restrainer for any reason.

- (XIII) Restraint Device Principles Which Reduce Stress On Animals And Help Reduce Vocalization—The behavioral principles of low-stress animal restraint and handling (Grandin, 1991b, 1993, 1994, 1995, 1996, 1998d and www.grandin.com) have been outlined in several publications and on the worldwide web. Pigs and cattle should enter a restraint device easily with a minimum of balking. Correcting problems with animal-
restraint devices can help reduce bruises and meat quality defects (e.g., blood-splash). The basic principles of low-stress animal restraint which will minimize vocalization and agitation are: (1) For cattle, block the animal’s vision with shields so that they do not see people or objects that move while they are entering the restrainer. Install metal shields around the animal’s head on box-type restrainers to block the animal’s vision. Alley-ways leading up to restraint devices should have solid sides. (2) Block the animal’s vision of an escape route until it is fully held in a restraint device (Grandin, 1995). This is especially important on restrainer conveyors. A flexible curtain of conveyor belts at the discharge end of the conveyor works well. Cattle often become agitated in a conveyor restrainer if they can see out from under the solid hold-down cover before their back feet are off the entrance ramp. Extending the solid hold-down cover on a conveyor restrainer will usually have a calming effect on animals and most animals will ride quietly. Solid hold-downs can also be beneficial for pigs on conveyor restrainers. (3) Eliminate air hissing and other distractions such as clanging and banging. (4) The restraint device must be properly lighted. Animals will not enter a dark place or enter a place where direct glare from a light is blinding them. To reduce balking at the entrance of a conveyor restrainer, install a light above the entrance. The light should be above the lead-up chute; it should illuminate the entrance of the restrainer, but it must not glare into the eyes of approaching animals. Light coming up from under a conveyor restrainer should be blocked with a false floor to prevent animals from balking at the “visual cliff effect.” (5) Provide non-slip flooring in box-type restrainers and a non-slip cleated entrance ramp on conveyor restrainers. Animals tend to panic when they lose their footing. (6) Parts of a restraint device operated by pneumatic or hydraulic cylinders that press against the animal’s body should move with slow steady motion. Sudden jerky motion excites animals. On existing equipment, install flow controls to provide smooth steady movement of moving parts which press against the animal. (7) Use the concept of optimum pressure. The restraint device must apply sufficient pressure to provide the feeling of being held, but excessive pressure that causes pain should be avoided. Install a pressure regulator to reduce the maximum pressure that can be applied. Very little pressure is required to hold an animal if it is fully supported by the device. If an animal bellows or squeals in direct response to the application of pressure, the pressure should be reduced. (8) A restraint device must either fully support an animal or have non-slip footing so the animal can stand without slipping. Animals panic if they feel like they may fall. Restraint devices should hold fully sensible animals in a comfortable, upright position. (9) Equip restraint devices with controls that enable the operator to control the amount of pressure that is applied. Animals of different sizes may require different amounts of pressure. Hydraulic or pneumatic system should have controls which enable a cylinder of the device to be stopped in mid-stroke. (10) Never hold an animal in a head restraint device for more than a few seconds. The animal should be stunned or ritually slaughtered immediately after the head holder is applied. Head restraint is much more aversive than body restraint. Animals can be held in a comfortable body restraint for longer periods if they are comfortable. The animal’s reaction should be observed. If the animal struggles or vocalizes, this is an indication that the device is causing discomfort. (11) Restraint devices should not have sharp edges that dig into an animal. Parts that contact the
animal should have smooth rounded surfaces and be designed so that uncomfortable pressure points are avoided. (12) On V-conveyor restrainers, both sides should move at the same speed.

With regard to animal restraint, it is possible, in most plants, to modify existing restraint devices to lower vocalization and agitation scores. Balking at the entrance is also easy to reduce. Most of the modifications that would reduce animal agitation and vocalizations can be installed at a minimum expense—usually between $200 to $2,000.

- (XIV) Considerations For Use Of Electric Prods—Reducing the use of electric prods will improve animal welfare. Many well-managed plants have eliminated use of electric prods in the holding pens. In beef plants with well-trained handlers, the survey (Grandin, 1997b) showed that 90 to 95 percent of the animals could be moved through the entire plant without the use of an electric prod. USDA regulations require that electric prods have a voltage of 50 volts or less. An easy way to test an electric prod to determine if it delivers too intense a shock is to touch an animal with the prod for one second; if such contact causes the animal to vocalize, the power should be reduced. Electric prods which have sufficient power to knock an animal down or paralyze it must not be used. Electric prods must never be applied to sensitive parts of the animal such as the eyes, ears, nose or anus.

- (XV) Use Of Electric Prods Efficacy Criteria—Below are two tables that characterize the method to be used for scoring plants for appropriate incidence of animals subjected to electric prods:

Table 1. Electric prod scoring criteria for cattle (percentages of animals prodded).

<table>
<thead>
<tr>
<th>Crowd pen to chute</th>
<th>Entrance of stunning box or restrainer</th>
<th>Total percentage of cattle prodded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>None</td>
<td>5% or less</td>
</tr>
<tr>
<td>Acceptable</td>
<td>5% or less</td>
<td>20% or less</td>
</tr>
<tr>
<td>Serious problem</td>
<td>---</td>
<td>50% or more</td>
</tr>
</tbody>
</table>

Table 2. Electric prod scoring criteria for pigs (percentages of animals prodded).

<table>
<thead>
<tr>
<th>Crowd pen to chute</th>
<th>Entrance of restrainer</th>
<th>Total percentage of pigs prodded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>None</td>
<td>5% or less</td>
</tr>
<tr>
<td>Acceptable</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Moral problem</td>
<td>---</td>
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</tr>
</tbody>
</table>

Electric prods should never be used on sheep.

- (XVI) Handling Recommendations To Reduce Electric Prod Use And Maintain Efficient Handling—Recommendations are as follows: (1) Remove or correct distractions which cause balking—Distractions caused by air hissing, shadows, reflections from shiny metal, ventilation drafts blowing in the faces of approaching animals, and seeing either moving people or moving machinery up ahead (Grandin, 1996) should be corrected. The evaluator can enter the chutes and observe those things that cause the animals to balk. Shields or strips of conveyor belting can be installed to prevent animals from seeing movement up ahead as they approach the restrainer or stunning box. Reflections can sometimes be eliminated by moving an overhead lamp. Ventilation drafts blowing down the chutes toward the animals may make it impossible to reduce electric prod use. The plant ventilation system may need to be adjusted. (2) Provide adequate lighting – Animals may refuse to enter a dark place. Entry into a restrainer can be facilitated by aiming a light into the entrance. The light must not shine into the eyes of approaching animals. Animals may be difficult to drive out of the crowd-pen and into the single-file chute if the chute is in the dark and the crowd-pen is brightly illuminated. Lighting problems can make quiet handling almost impossible. A common problem with lighting is that a handling system may work well when lamps are new, but the animals will balk more and more as lamps dim with age. The most efficient lighting can be determined by experimenting with portable lights. Animals may also balk at shiny reflections from a piece of metal or from sparkling water on the floor. (3) Reduce noise – Animals are very sensitive to high-pitched noise. Reducing high-pitched noises generated by motors and/or hydraulic systems can improve animal movement. Clanging and banging metal should be reduced and hissing air should be muffled. (4) Move small groups – When cattle and pigs are being handled, the crowd-pen and the staging areas which lead up to the crowd-pen should never be more than three-quarters full. Half full is best. Crowd gates should not be pushed up tightly against the animals. Cattle and pigs need room to turn. For sheep, large groups may be moved and the crowd-pen can be filled completely. (5) Use other driving-aids – Electric prods should be replaced whenever possible with other driving-aids such as a plastic paddle, a stick with a flag on the end or panels (for pigs). The animals should move easily and handlers should not hit them. Cattle and pigs can often be moved through a chute by having the handler walk by them in the opposite direction of desired movement. When the handler passes the shoulder of each animal, it will move forward. Grandin (1991a) provides more information on animal handling principles. (6) Use genetics and management to reduce incidence of excitable animals – There are some animals which have a very excitable temperament and are difficult to drive. Some lean pigs and cattle are very excitable (Grandin, 1991a, 1993b, www.grandin.com); these animals will often have high vocalization scores. Plant management personnel need to work with producers to
solve this problem. Pigs with excitable genetics will be easier to handle at the meat packing plant if producers have walked through the pens every day during the finishing period; only 10 to 15 seconds per pen is needed. Such interaction trains excitable pigs to be more comfortable with human handling. Producers should be encouraged to produce animals—genetically—which will be reasonably easy to handle.

- (XVII) Considerations For Movement To Stunning/Sticking Of Non-Ambulatory Animals—Each plant should develop written guidelines and procedures for handling non-ambulatory animals in a humane manner. Dragging sensible non-ambulatory animals is a violation of The Humane Slaughter Act regulations. Stunned, non-ambulatory animals may be dragged. If a skid loader (“Bob Cat”) is used to transport non-ambulatory pigs or sheep, the animal must be rolled into the bucket. Two people are required unless the loader is equipped with a special bucket with a lid; one person operates the loader and the other rolls the animal into the bucket. Loading a non-ambulatory animal into the bucket by shoving it up against a wall or fence is not acceptable. Shoving bare forklift forks under non-ambulatory cattle is not an acceptable method for moving them.

Plant personnel should develop procedures to help reduce the occurrence of non-ambulatory animals on the premises. Non-slip flooring is essential. Mounting activity and animal fights can cause injuries; this is especially a problem with bulls and boars. Bulls which are mounting other animals should be placed in a separate pen. Mounting by bulls is a common cause of bruising and crippling injuries to cows.

- (XVIII) Considerations For Pen Stocking Density. Pens should be stocked using recommendations of the Grandin (1991a) guidelines. A good rule-of-thumb is that all animals must have room to lie down simultaneously. All animals must have access to water to comply with the regulations of the Humane Slaughter Act.

- (XIX) Considerations For Maintenance Of Facilities And Equipment. Pens, alleys, chutes, restraints and other equipment should be kept clean and well maintained. They should be free of protrusions which could injure animals.

- (XX) Conclusion. An acceptable level of animal welfare can be maintained if scores at the critical control points for stunning, animal insensibility, slipping and falling, vocalization and electric prod use are in the acceptable range. Scoring performance for these variables is simple and easy to do under commercial plant conditions. Electrical stunning equipment must have amperage, voltage, and frequency parameters which have been verified by either electrical or neurotransmitter recordings from the brain to reliably induce insensibility. Plant managers must be committed to good animal welfare. Plants which have managers who insist on good handling and stunning practices will usually have animal welfare practices that are superior to those of plants in which management and supervision are lax. Since this paper was written in 1999, handling and
stunning in North American plants has greatly improved due to audits by restaurant companies. See the survey section of www.grandin.com.

**STUNNING METHOD AND BLOOD-SPASH**

The major negative effect on meat quality of inappropriately administered stunning methods is that they affect the incidence of petechial hemorrhages or blood-splash in the meat. Blood-splash is a cosmetic defect and it occurs when small capillaries in the muscle rupture while the circulatory system is still intact. Blood-splash can appear as small red spots or it can cover a larger area and look like a bruise. Blood splash is a meat quality problem that has no effect on animal welfare.

Lambooy and Sybesma (1988) stunned pigs with 70 volt or 475 volt electricity, in the fattening pen vs. in a restrainer and using electrical stunning vs. CO2 stunning and reported that: (a) high voltage and stunning in a pen resulted in lower incidences of blood-splash, and (b) CO2 stunned pigs showed no blood-splash. Grandin (1988b) compared pig-handling treatments that consisted of Control Treatment (4-6 seconds stunning time; electric prods; 10 minutes rest after climbing a long ramp) vs. Special Treatment (3-4 seconds stunning time; no electric prods and overnight rest prior to stunning) and concluded that Special Treatment handling provided the greatest reduction in petechial hemorrhages when low winter temperatures had greater day-to-day variability.

The incidence of blood-splash and hemorrhages is increasing in both beef and pork. The most likely cause of this increased incidence greater emphasis in animal selection on leanness in beef and pork. Leanness is probably associated with increased fragility of the animal’s capillaries and, thus, with an increase in the incidence of blood-splash.

Recent audits of pork and beef packing plants by the National Pork Producers Council and the National Cattlemen’s Association indicate that blood-splash is costing the pork industry almost 50 cents for every hog marketed (Morgan et al., 1993) and is costing the beef industry about 12 cents for every slaughter steer or heifer marketed (Smith et al., 1994). In the pork industry, damage to loins and hams is costing approximately $43 million annually (Morgan et al., 1993).

Sensitivity of individual animals to blood splash differs greatly. Unstable weather, especially circumstances in which ambient temperatures quickly fluctuate, can make animals more sensitive to such damage. Grandin (1988b) found that fluctuating weather affected the efficacy of electrical stunning in terms of reductions in blood-splash in pigs. Therefore, when a new stunning or handling procedure is studied, for its effectiveness in reducing blood-splash, it must be tested on alternate days, against a control method, for several weeks to remove confounding due to temperature and weather fluctuations. Seasonal differences in blood-splash have also been reported in
Research has demonstrated that an automatic stunning system mounted on a center track (double rail) restrainer reduced blood splash by 20 percent compared to a standard V-conveyor restrainer. On V-conveyor restrainers, blood-splash will increase if one side of the conveyor runs faster than the other (Grandin, 1985). Carbon dioxide stunning will produce less blood-splash than does the average electrical stunner (Channon et al., 1998). However, tests run in a single plant with CO2 versus a well-maintained and operated electrical stunner showed no differences in incidence of blood-splash. Electrical stunning is comparable to CO2 stunning from a blood-splash standpoint, if it is done perfectly. The most serious problem with blood-splash incidence is in terms of its association with ultra-lean pigs with very heavy muscling. CO2-stunning probably has little advantage over electrical stunning for use with normal pigs but it is most likely to provide a reduction in blood-splash in ultra-lean pigs. Some pigs with extremely muscling have very weak skeletons which increases the incidence of broken backs and damage to the loins during stunning.

The first step in reducing blood-splash is to stop double-stunning; double-stunning occurs when an animal is given two separate jolts of electricity. Practical experience has shown that blood-splash can be greatly reduced by following the stunning practices that are outlined below. Double-stunning damages the capillaries because it makes the muscles contract twice. To prevent this, the operator must press the wand firmly against the pig before the stunning current is turned on. The wand must remain pressed against the pig until the timer stops the flow of current. If the wand slides during the stun, blood-splash incidence may increase. A stunning switch with dirty contacts or a cord with frayed wires inside may also cause blood-splash, because they can allow fluctuations in the electrical current due to the momentary making and breaking of the circuit. Wiring and switches need to be changed frequently to prevent fluctuations in the electrical current. It is also essential to clean electrode contacts every day and make sure the pigs are wet.

Some plants have attempted to reduce blood-splash by reducing the stunning amperage to 0.5 amps. This is a practice that should be banned. Scientific research has shown that a minimum of 1.25 amps at 250 to 300 volts must pass through the hog’s brain to induce instantaneous unconsciousness (Hoenderken, 1983). Use of lower amperages will kill the pig, but the animal may feel the symptoms of a heart attack.

The plants with the lowest incidence of blood-splash in North America use 1.25 amps with an electronic amperage-controlled circuit. Unlike old-fashioned voltage-regulated stunners the amperage in electronic amperage-controlled circuits is kept constant at 1.25 with the electronics and the voltage automatically changing with resistance encountered in individual hog.
A survey of seven large pork plants conducted by a major processed-products firm indicated that the one plant that used an electronic amperage-controlled stunner had a 100 percent reduction in blood-splash compared to use of the old-fashioned, voltage-regulated stunner. The concept is very simple; the amperage should be held absolutely constant at 1.25 amps while the voltage is allowed to vary. There is no reason to stun hogs with 0.5 amps. An electronic system with constant amperage will generate less blood-splash than will use of a voltage-regulated system at 0.5 amps. Electronic amperage-controlled electrical stunners are now available with computer outputs that count double-stuns and misapplied stuns. The printouts show that an operator’s performance declines after about two hours; the operators should be rotated every few hours to prevent fatigue from increasing blood-splash.

There has never been a test comparing CO2 stunning to electronically controlled constant amperage electrical stunning in the same plant. The test described previously, in which CO2 stunning and electrical stunning were compared in the same plant, involved use of an old-fashioned voltage-regulated stunner. It is likely that electronically amperage-controlled electrical stunning, if it is perfectly maintained and operated, will generate the same incidence of blood-splash as will CO2 stunning. The principles described above apply to both manual and automatic stunners.

**Quick bleeding.** It is essential that animals are bled quickly. The animal should be stuck within 15 seconds after stunning. This will reduce blood-splash in all species (Burson et al., 1983; Van de Wall, 1978). Bleeding very quickly reduces blood-splash because quickly lowering the blood pressure helps prevent small capillaries from bursting.

**Electrical stunning of cattle.** Blood-splash problems are the main reason why electrical stunning has not become more popular for use with cattle. Plant managers in New Zealand have found that blood-splash incidence is low in grass-fed cattle, but when the Australians tried electrical stunning in fed cattle, blood-splash levels were too high to make it commercially viable. Practical experience in New Zealand has shown that very quick bleeding (within 10 seconds) is required to keep blood-splash incidence low.

**Resting and handling animals.** Practical experience in many pork slaughter plants reveals that pigs should be rested for 2 to 4 hr to reduce incidences of both blood-splash and pale, soft, exudative (PSE) lean. In cattle, long resting periods are not recommended, but it is advisable to allow the animals about 30 minutes to settle-down after unloading. Such rest will help prevent excitement during subsequent handling. Reducing or eliminating electric prod usage also helps to reduce occurrence of blood-splash. Calkins et al. (1980) found that electric prods increased incidence of blood-splash in pigs. Practical experience in many slaughter plants has shown that using very low voltage prods, with 24 volts or less, reduced blood-splash. If pigs squeal when
electrically prodded they are receiving a shock that is too strong.

**Captive-bolt stunning.** Some beef plants have found that a cartridge-fired stunner causes less blood-splash than does use of a pneumatic stunner. There are two possible explanations for these differences. First, some air-operated stunners inject air into the brain. The second explanation is that poor maintenance of captive-bolt stunners or differences in shooting position can cause increases in blood-splash. Some operators using air-operated stunners will shoot cattle behind the poll because the air-powered stunner may be harder to position on the forehead than is the cartridge-fired stunner. A test conducted in one plant with a highly skilled operator using perfectly maintained equipment showed no difference in incidence of blood-splash. Pneumatic guns require careful maintenance and some plants skimp on maintenance resulting in excessive recoil and poor stunning.

There is also concern that pneumatic stunners that inject air could contaminate beef by forcing brain tissue throughout the body. Recent research (Schmidt et al., 1998) showed that air injection sometimes forced pieces of neurological tissue as large as a pencil into the heart and other organs. This problem was not observed when a cartridge-fired stunner was used. For food-safety concern reasons, the use of stunners that inject air into the head is not recommended. One major beef packing company has found that the extra cost of blank cartridges for a cartridge-fired stunner was economically justified because eliminating air injection reduced occurrence of blood-splash.

**Ritual slaughter.** Cattle and calves slaughtered without stunning (ritual slaughter of Jews—kosher—and Muslims—halal) are more prone to blood-splash than are cattle stunned by use of either type of captive-bolt stunner. Cutting the throat of cattle and calves without first stunning them almost always increases incidence of blood-splash. Blood-splash incidence in cattle stunned with a captive-bolt stunner is almost always under 0.5% percent; but, in ritually slaughtered cattle, blood-splash often occurs in 3% to 10% of cattle.

Keeping cattle calm during ritual slaughter will reduce occurrence of blood-splash because excited cattle often have a bigger spasm when they lose consciousness (Grandin, 1994). Restraint devices should be designed to apply as little pressure as possible to the animal’s body. After the throat is cut, restraining devices should be loosened immediately. Cattle should be ritually slaughtered within seconds after their heads are restrained in the neck yoke; allowing an animal to fight restraint will increase incidence of blood-splash.

The technique used in throat-cutting can also affect the incidence of blood-splash and the speed of bleed-out. Cutting the throat too far back on the neck slows bleed-out and increases blood-splash. The incidence of blood-splash can differ greatly between two different ritual slaughterers. Stunning cattle with a captive-bolt device will greatly
reduce incidence of blood-splash caused by ritual slaughter. Some religious authorities will permit post-slaughter stunning of animals. Stunning with a captive-bolt device, immediately after ritual slaughter, will lower blood-splash incidence from 3%, in the best ritual slaughter plant, to about 1%; such incidence will still be slightly elevated as compared to stunning the bovine prior to bleeding.

Gregory et al. (1988), studying bobby calves in Australia, determined that a faster bleed-out was obtained when the thoracic, compared with the neck, sticking protocol was used, and when electrical stunning rather than captive-bolt stunning was used. Bager et al. (1998) reported that the amounts of jugular blood that were collected from calves that were exsanguinated by throat-cutting indicated that cerebral blood perfusion is very severely impaired after gash-cutting while cortical dysfunction occurred at a time when mean arterial blood pressure was sufficiently high to maintain cerebral circulation. They regarded those findings and indirect evidence of a retrograde flow of blood from the vertebral arteries, through the occipito-vertebral anastomis, to the open cephalic ends of the severed carotid arteries.

Due to differences in the anatomy of the blood vessels in cattle and sheep, ritual slaughter will not increase blood-splash in sheep. Almost the entire blood supply to the brain of a sheep is in the front of the neck whereas cattle have some small vessels in the back of the neck. This difference in anatomy causes sheep to bleed-out more quickly.

REFERENCES


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