Meat Science and Applications

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# Antemortem Handling and Welfare

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I. INTRODUCTION

The Humane Slaughter Act of 1978 in the United States and laws in many other countries require that animals be rendered insensible to pain prior to any slaughtering procedures (1). The meat-buying public is becoming increasingly concerned about how farm animals are raised, transported, and slaughtered (2). Maintaining high standards during handling and stunning should also be done because it is the right thing to do. Quiet handling of livestock and proper stunning procedures will also provide economic benefits by reducing meat quality defects such as PSE (pale, soft, exudative) pork, dark cutters, and toughness in beef and bruises (3,4). In plants processing large animals such as cattle, careful, quiet handling will also help improve safety and reduce employee injuries. Large animals are dangerous when they become agitated.

II. CONTINUOUS MEASUREMENT AND MONITORING

People who handle and stun hundreds or even thousands of animals often become numb and desensitized to animal suffering (5). The author has observed that handling and stunning procedures have a tendency to become rough and careless unless they are continuously monitored. The manager who is most effective in maintaining high standards of animal welfare must be involved enough to care, but not so involved in day-to-day operations that he or she becomes desensitized.

The author strongly recommends using a HACCP-type approach to measuring the efficacy of stunning and the performance of animal handlers. The objective scoring system is described fully in Grandin (6,7). The five major critical control points of stunning and animal handling are briefly outlined here and more information on proper stunning methods will be in the section on stunning. Each critical control point is measured on a yes/no basis for each animal. Fifty to one hundred animals should be scored each week.

1. **Stunning efficacy.** Percentage of animals rendered insensible on the first attempt.
2. **Bleed rail insensibility.** Percentage of animals that remain insensible before and after bleeding.
3. **Vocalization.** Percentage of cattle or pigs that vocalize (bellow, moo, or squeal). Vocalization in cattle and pigs is highly correlated with physiological stress measurements and adverse events such as missed stuns, excessive electric prod use, excessive pressure from a restraint device, slipping or falling, surgery, and isolation of a single animal (8–11).

Each pig or bovine is scored as either a vocalizer or non-vocalizer during handling and stunning. Vocalization scoring is done in the crowd pen, single file race, stunning box, restrainer, shackle area, and bleed rail. Vocalization is not scored while animals are standing in the holding pens because cattle standing undisturbed often vocalize to each other. In large plants where counting of indi-
individual pigs squeals is difficult, a sound level meter can be used. If an animal is immobilized with electricity it may still be conscious but unable to vocalize. This is extremely distressful for animals and must not be used as a method to keep conscious animals still (12–14). Electro-immobilization must not be confused with electrical stunning, in which a high amperage current is passed through the brain. Vocalization scoring should not be used on sheep because sheep walking quietly up a race often vocalize to each other.

4. Slipping and falling. Percentage of animals that slip or fall during handling and stunning. This is scored in all areas from the unloading ramp to the stunning box or restrainer.

5. Electric prods. Percentage of animals prodded with an electric prod (goad). Reducing the percentage of animals shocked with an electric goad reduces stress and improves welfare.

Audits of these five critical control points must be done on a regular basis, the same way microbiological audits are conducted. Bacteria counts would increase and sanitation procedures would become sloppy unless continuous monitoring was done. Handling and stunning must be audited the same way. One factor that contributes to a deterioration of handling and stunning practices is that the only variable that is measured in the stunning area of many plants is gaps in the production line and speed. When worker evaluations are based on gaps in production, this tends to encourage abuse.

III. MEAT QUALITY CORRELATIONS

Measurements of meat quality and bruises are important. Progressive plant managers have found that quiet handling in the stunning area will reduce PSE (pale, soft, exudative) in pork. In four different plants, the author found that reducing electric prod use and the quiet handling of pigs resulted in 10% more pork that was suitable for high quality export to discriminating customers in Japan. Improved export pass rates will be correlated with reduced squealing. An overemphasis on preventing gaps in the production line may result in more animal stress and increase meat quality problems. Many plant managers base plant performance on keeping the processing line full because processing line gaps are measured and losses due to poor animal handling are often not measured. Handling must be measured on a regular basis to maintain high standards. Animal welfare is also part of quality. Two of the major hamburger chains are using HACCP type audits of animal handling and stunning. They are done in the same manner as microbiological audits.

IV. HOW STRESSFUL IS SLAUGHTER?

Animal handling, both on the farm and in the slaughter plant, will cause physiological measures of stress to increase. When animals become agitated during handling, it is most likely because of fear. The fear circuits in animal brains have been completely mapped (15,16,17). Grandin (6) reviewed numerous studies of cortisol (stress hormone) levels during handling both on the farm and at slaughter. The range of values were similar for cattle on farm restraint in a squeeze chute and during slaughter. The range of average values was 24 ng/ml to over 63 ng/ml (8, 18–24). Rough handling, slipping on the floor, and electric prod use resulted in higher cortisol levels of 63 ng/ml. The highest average level recorded in a slaughter plant was 93 ng/ml (8). Cattle were inverted on their backs for 103 seconds prior to ritual slaughter. Properly performed cattle slaughter seems to be no more stressful
than on farm restraint. One must remember that cortisol is a time-dependent measure. Twenty minutes is required to reach peak value (22,23).

V. CAUSES OF POOR WELFARE AUDIT SCORES

When an audit reveals poor performance, management must determine the exact cause of the problem. The correct diagnosis of problems can help avoid costly purchases of new equipment. Many managers have a tendency to assume that equipment may have to be replaced when a problem could be easily fixed without a major expense. The major causes of high percentages of animals vocalizing or excessive electric prod use are:

1. People using improper handling procedures. This is usually the number one problem. The author has observed that the two most common animal handling mistakes are overloading crowd (forcing) pens and overuse of electric prods. Pigs and cattle need room to turn. Crowd pens should be filled only half full (Fig. 1). Moving small groups of pigs and cattle will facilitate handling. Sheep can be moved in larger groups because this species has more intense following behavior.

2. Distractions that cause balking. This is the second most common problem. All species of animals may balk and refuse to move when they see things in the race that scare them, such as sparkling reflections, dangling chains, moving people or equipment, shadows, or water dripping (24,25). A calm animal will stop and look right at the distractions that scare it (Fig. 2). You should crouch down and

Figure 1  The crowd pen should be filled only half full, as shown in this photo. These people are using excellent handling methods. The crowd gate should not be pushed up tight against the animals.
look up the race to see what the animals are seeing. It is important to get right down at the animal’s eye level. Shields can be installed to prevent animals from seeing moving people or objects up ahead. One of the worst causes of balking is air blowing down the race into the faces of approaching animals. Animals also balk and may refuse to enter a dark place. They have a tendency to move from a darker place to a brighter place (26,27). Adding a light to illuminate a race entrance (Fig. 3) or moving a lamp to eliminate a sparkling reflection will often improve animal movement. If air is blowing toward the animals, the plant ventilation should be changed. Simple inexpensive changes can often greatly improve animal movement. People who are working to remove the distractions that impede animal movement must be very observant of small details that may be insignificant to them. A person may not notice a sparkling reflection, but the animal does. Animals should move through the system easily. If they balk, you should find the distraction that is causing balking instead of increasing electric prod usage. In the very best systems, 95% of the cattle could be moved through a slaughter line that processed over 200 cattle per hour without an electric prod.
Figure 3  This spotlight illuminates the restrainer entrance and will facilitate cattle entry. Animals tend to approach lighted areas.

There will be more information on facilitating animal movement in the behavior and equipment design sections.

3. Equipment maintenance. Poor maintenance of captive bolt guns is a major cause of poor stunning (7). Employees will become frustrated and will be more likely to handle animals in a rough manner if they are frustrated because gates are broken or other equipment is malfunctioning.

4. Equipment design. This is discussed in the equipment section.

5. Genetic predisposition to excitability. Some animals have a very excitable temperament and are difficult to drive. Some lean pigs and cattle are very excitable (28–30). These animals will often have high vocalization scores. Pigs from certain farms were more difficult to drive than pigs from other farms (31). Plant management should work with producers to solve this problem. Pigs with "excitable genetics" will be easier to handle at the slaughter 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. Pigs that had been walked in the alley during finishing were less excitable and easier to handle (25,28,32). Producers should be encouraged to produce animals that will be reasonably easy to handle.

Another problem the author has observed are extremely wild cattle that become highly agitated and difficult to handle at a slaughter plant (33). This problem is caused by both genetics and previous experience with handling. Cattle with an excitable temperament that are raised on large pastures where they seldom see people should be exposed to people on foot, months before they arrive at a slaughter plant. The author has observed that cattle that have never seen a person on foot can be difficult and dangerous to handle. These very wild cattle are also more likely to get bruises or have meat with quality problems such as dark cutters. Ranchers should be encouraged to get their animals accustomed to people on foot.
VI. ANIMAL VISION, HEARING, AND SMELL

A. Vision

Ruminant animals can discriminate among different colors (34). The latest research shows that sheep, goats, and cattle are dicromats, which means that they may be partially color blind. The cones in the ruminant eye are most sensitive to yellowish green light (552 to 555 nm wave length) and blue (444 to 455 nm) (35). Ruminants lack cones that are maximally sensitive to the color red. Practical experience has shown that cattle and pigs are very sensitive to anything that has high contrast. This causes them to balk at drain grates or a change from a concrete to metal floor (27,29,36). Lighting should be even and diffuse, and harsh contrasts of light and dark should be avoided. Cattle and other grazing animals have wide-angle vision and they can see in excess of 300° (37). To prevent the animals from becoming scared of distractions outside the race, stunning boxes, races, and crowd pens should have solid fences. The crowd gate should also be solid.

B. Hearing

Cattle and sheep have very sensitive hearing. They are more sensitive to high-frequency noise than people and they are especially sensitive to high-frequency sound, around 7000 to 8000 Hz (38). Humans are more sensitive to 1000–3000 Hz (38). Cattle can easily hear up to 21,000 Hz (39) and there is also evidence that cattle have a lower hearing threshold than people (40). This could mean that sounds that may not bother people may hurt the animals’ ears. Intermittent noise is very aversive to pigs (41).

Reducing noise will improve animal movement. High-pitched noise is worse than low-pitched noise. Employees should not yell, whistle, or make loud noises; clanging and banging equipment should be silenced by installing rubber stops, and noisy air exhausts should be piped outside or silenced with inexpensive mufflers (muffling devices wear out and should be replaced every 6 months to keep noise levels low). Hissing air is one of the worst noises, but it is also the easiest to eliminate.

A high-pitched whine from a hydraulic pump or undersized plumbing is disturbing to animals and can make them balk. At one plant, installing larger-diameter plumbing to eliminate a high-pitched whine from a hydraulic system resulted in calmer, easier to move animals. In another plant, excessive noise from ventilation fans made pigs balk. Noise from the fans increased as the pigs approached the restrainer. Noise increases physiological stress levels. Slaughter in a quiet research abattoir resulted in lower cortisol levels compared with slaughter in a large noisy commercial plant (42).

When new systems are built, there needs to be more emphasis on noise reduction. Recently, the author visited an up-to-date pork slaughter plant. Over 800 pigs per hour were quietly moved through the plant with very little balking. The race system, overhead conveyors and restrainer system were engineered to greatly reduce noise. Gates had rubber pads to prevent clanging and banging; motors and conveyors were designed to reduce high-pitched noise. Well-trained handlers quietly moved the pigs up the race with very little squealing.

The type of building used in the animal handling area will also influence sound levels. Buildings constructed from pre-cast concrete with a high ceiling will have higher sound levels due to echoes than a building constructed from cooler board panels that have foam insulation sandwiched between two pieces of metal. Lowering the ceiling can sometimes help reduce sound levels. Hanging baffles from the ceiling may also help.
C. Smell

Many people interested in the welfare of livestock are concerned about animals seeing or smelling blood. Cattle will balk and sniff spots of blood on the floor (36); washing blood off facilitates movement. Balking may be a reaction to novelty. A piece of paper thrown in the race or stunning box elicits a similar response. Cattle will balk and sometimes refuse to enter a stunning box or restrainer if the ventilation system blows blood smells into their faces at the stunning box entrance. They will enter more easily if an exhaust fan is used to create a localized zone of negative air pressure. This will suck smells away from cattle as they approach the stunning box entrance.

Observations in kosher slaughter plants indicate that cattle will readily walk into a restraining box that is covered with blood. In Jewish ritual (Kosher) slaughter, the throat of a fully conscious animal is cut with a razor sharp knife. The cattle will calmly place their heads into the head restraint device and some animals will lick blood or drink it. Kosher slaughter can proceed very calmly with few signs of behavioral agitation if the restraining box is operated gently (43). However, if an animal becomes very agitated and frenzied during restraint, subsequent animals often become agitated. An entire slaughter day can turn into a continuous chain reaction of excited animals. The next day after the equipment has been washed the animals will be calm. The excited animals may be smelling an alarm pheromone from the blood of severely stressed cattle. Blood from relatively low-stressed cattle may have little effect. However, blood from severely stressed animals, which have shown signs of behavioral agitation for several minutes, may elicit a fear response.

Eibl-Eibesfeldt (44) observed that if a rat is killed instantly in a trap, the trap can be used again. The trap will be ineffective if it injures and fails to kill instantly. Research with rats supports this idea. Rats showed a fear response to the blood of rats and mice that had been killed with carbon dioxide (45,46).

Recent research with pigs and cattle indicates that stress pheromones are secreted in the saliva and urine. Vieville-Thomas and Signoret (47) and Boissey (48) both report that pigs and cattle tend to avoid objects or places that have urine on them from a stressed animal. This stress response is not instantaneous. The stressor was applied for 15 to 20 minutes to induce the effect. In the cattle experiment, cattle were given repeated shocks during a 15-minute period.

VII. BASIC HANDLING PRINCIPLES

The first principle of animal handling is to avoid getting the animal excited. It takes up to 30 minutes for an animal to calm down and have its heart rate return to normal after it has been handled roughly (49). Calm animals move more easily and they are less likely to bunch together and be difficult to remove from a pen. Handlers should move with slow deliberate movements and refrain from yelling. Recent research by Joe Stookey and Dr. Waynert at the University of Saskatchewan (50) has shown that whistling and yelling is more stressful than hearing a gate slam.

All species become agitated when they are isolated from other animals. In sheep and cattle, isolation can cause cortisol levels to rise (52,53). Cattle, elk, bison, and other large animals can become agitated and very dangerous when isolated. If an isolated animal becomes agitated, other animals should be put in with it. Electric prods should be replaced as much as possible with other driving aids such as sticks with flags on them or
Figure 4  Cattle can be easily turned and moved by shaking a stick with plastic streamers on it by their head.

panels for pigs (Fig. 4). A piece of plastic fabric that is stiffened on the top with a rod makes a good tool for moving pigs down an alley. Handlers also need to learn how to use following behavior. The crowd pen should not be filled until there is room in the single file race for the animals to enter. If the single file race is full, animals in the crowd pen will turn around. Good handling requires paying attention to many small details of exactly how to do a procedure. The crowd pen and the alley that leads to it from the yard should be filled only half full.

Handlers must also be careful not to force animals with crowd gates. This is especially a problem with power crowd gates. If a system is designed and operated correctly, animals should walk up the race without being forcibly pushed. When animals are pushed up too tightly with a power crowd gate, handling becomes more difficult. Tightly packed animals are unable to turn around to enter the race.

VIII. HANDLER MOVEMENT PATTERNS

People who handle animals need to understand the principles of the flight zone and point of balance (Fig. 5) (25,53,54). Handlers should work on the edge of the animal’s flight zone. Flight zone size depends on the wildness or tameness of the animal. A completely tame animal has no flight zone and may be difficult to drive. To make an animal move forward, the handler must be behind the point of balance at the shoulder. To back it up, he or she stands in front of the point of balance. Figures 6 illustrates handler movement patterns that make it possible to greatly reduce the usage of electric prods. Cattle, pigs, or sheep will move forward in a race when a handler walks quickly past the animal in the opposite direction of desired movement. The handler must move quickly past the point of balance at the shoulder to induce the animal to move forward. The animal will not move forward until the handler passes the shoulder and reaches the hips.
IX. DESIGN OF HANDLING FACILITIES

A. Nonslip Flooring

A minimum essential for all species is nonslip flooring. Careful, quiet handling is impossible if animals slip or fall. Slipping in a cattle stunning box will cause animals to become agitated and difficult to stun. A grating constructed from 2 cm diameter steel bars welded in a 30 cm by 30 cm grid will prevent slipping in high traffic areas where floors have become worn.

Figure 5  Diagram of the flight zone and point of balance. Handlers should work on the edge of the flight zone. Entering the flight zone in the area marked by the letters will make the animals move.

Figure 6  Handler movement pattern to induce an animal to move. When the handler walks back past the point of balance in the opposite direction of desired movement, the animal will move forward. The animal moves in the opposite direction when the handler passes the balance line.
B. Pen Space

Stockyard or antemortem pens must provide enough space. The American Meat Institute (55) has guidelines for minimum pen space requirements. Many countries have Codes of Practice that stipulate the amount of pen space required. A good rule of thumb is that there should be sufficient space for all the animals to lie down at once. In the United States, the Humane Slaughter Act of 1978 requires that all holding pens be equipped with water troughs or some other watering device. In hot weather, pigs require additional space to prevent death losses due to heat stress.

C. Design of Races and Crowd Pens

Detailed information of race and crowd pen designs can be obtained in Grandin (28,29,56,57). There are three major design mistakes that can make quiet, calm handling extremely difficult: a single-file race that is too wide; a race that appears as a dead end; and a crowding pen on a ramp. Single-file races and stunning boxes must be narrow enough to prevent animals from turning round or becoming wedged beside each other. A cattle race should be 76 cm wide, and races for pigs should have only 3 cm of clearance on each side of the largest pigs. For cattle, a curved race is more efficient (29). Curved races work well because animals entering the race cannot see people or other activity up ahead (Fig. 7). However, a curved race must be laid out correctly. If it is bent too sharply at the junction between the single-file race and the crowding pen, the animals may refuse to enter because the race entrance appears to be a dead end. Curved races must be laid out so that animals standing in the crowding-pen can see a minimum of three body lengths up the race before

Figure 7  A curved race is more efficient than a straight one because the animals cannot see people up ahead. Solid sides that prevent the animal from seeing outside the race will keep animals calmer.
it turns. Correct curved race layouts are shown in references (28,56,57). Weeding (58) illustrated a pig race that is laid out wrong: the race looks like a dead end to the pigs and this system increased stress.

Another serious design mistake is to build a crowding pen on a ramp. In facilities where a ramp is required to reach the stunning box or restrainer, it should be located in the single-file race. Groups of animals in a crowding pen will tend to pile up on the back gate if the crowding pen is located on a ramp. Cattle and sheep will readily move up a ramp but pigs will move easier in a level system with no ramps. New pig handling facilities should be level.

X. DESIGN AND OPERATION OF RESTRAINT DEVICES

In small plants with line speeds of under 240 pigs per hour, it was less stressful to electrically stun pigs with hand-held tongs while they were standing in groups on the floor (10) compared to moving them through a single-file or double-file race. At higher speeds, floor stunning with tongs tends to become rough and sloppy. Whereas cattle and sheep move easily through a single-file race, pigs tend to be more difficult to drive. This is a species difference: cattle and sheep naturally move in single file whereas pigs do not. Cattle and sheep will move very easily and quietly through a well-designed single-file race.

Design of animal restraint devices for both conventional slaughter where the animal is stunned and ritual slaughter are covered in detail in Grandin (5,28,29,43,59,60). The behavioral principles of low stress restraint are as follow:

1. Animals should never be left in a stunning box or restraint device. Stun or ritualistically slaughter immediately after the animal enters.
2. Animals should enter the device easily. If they balk, check for distractions discussed previously. A lamp can be used to illuminate the entrance. It must provide indirect lighting. On devices that are above the floor, install a false floor to prevent the entering animal from perceiving the visual cliff effect (59,60). Ruminants can perceive depth (61).
3. Block the animal’s vision so that it does not see people or suddenly moving objects. Install metal shields around the animal’s head on box-type restrainers. This is not necessary on conveyor restrainers because the next animal sees the animal in front of it. Block the animal’s vision of an escape route until it is fully held in a restraint device (60). This is especially important on restrainer conveyors. Cattle often become agitated in conveyor restrainers if they can see out from under the 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 and most cattle will ride quietly. Solid hold downs can also be beneficial for pigs on conveyor restrainers. Experiment with pieces of cardboard to figure out the best locations for shields to block the animal’s vision.
4. Provide nonslip flooring in box-type restrainers and a nonslip cleated entrance ramp on conveyor restrainers. Animals tend to panic when they lose their footing.
5. Parts of a restraint device that press against the animal’s body should move with slow steady motion. Sudden jerking motion excites animals. On existing equipment, install inexpensive flow controls to provide smooth steady movement of moving parts that press against the animal.
6. 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.

7. A restraint device must either fully support an animal or have nonslip footing. Animals panic if they feel as if they may fall. Restraint devices should hold fully sensible animals in a comfortable, upright position.

8. Equip restraint devices with controls that enable the operator to control the amount of pressure that is applied. Different-sized animals may require differing amounts of pressure. Hydraulic or pneumatic systems should have controls that enable a cylinder on the device to be stopped in mid-stroke.

9. 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.

10. The operator must be adequately trained and supervised. One big problem in many slaughter plants is that the people who handle and stun animals are the lowest paid in the plant. In England, their pay has been raised and people who stun animals must be licensed.

XI. STUNNING

A good stunning method must render an animal completely insensible, similar to a state of surgical anesthesia. Some stunning methods are reversible, such as head-only electrical stunning, and unless the animal is bled quickly it will return to consciousness. Other methods such as penetrating captive bolt or cardiac arrest electrical stunning irreversibly start the process of death.

A. Electrical Stunning

To induce instantaneous insensibility electrical stunning must induce an epileptic state in the brain (62–64). The electrodes must be positioned so that the electric current passes through the brain (Fig. 8). Electrical parameters such as amperage, voltage, and frequency must be verified with the use of either electrical or chemical measurements from the brain to induce instant insensibility (6). Insufficient amperage can cause an animal to be paralyzed without losing sensibility. This would cause suffering.

Berghaus and Troeger (65) evaluated animal welfare implications of higher-frequency (500 or 800 Hz) head-only electrical stunning in comparison to "normal" (50 Hz) stunning. (In head-only stunning an electric current is passed through the brain by two electrodes positioned on the head.) They 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 × 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). Higher frequencies are being used to help reduce petechial hemorrhages (blood splash) in the meat. The use of higher stunning frequencies did not result in a reduction of time of unconsciousness under laboratory conditions, as was de-
Figure 8  Head-to-back cardiac arrest electric stunning of sheep. The head electrode must be positioned so that the current passes through the brain.

scribed by Anil and McKinstry (66). 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. More information on the use of high frequencies to stun pigs can be found in Simmons (67).

For market-weight pigs, a minimum of 1.25 amps is required (63). For sheep, a minimum of 1.00 amp is required (68,69). These amperages must be maintained for one second, during stunning, to induce instant insensibility. The Council of Europe (1991) recommends use of the aforementioned 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 ensure insensibility (70). Research has also shown that too high an electrical frequency will result in failure to induce insensibility. Warrington (64) 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 (71,72). However, in pigs weighing under 200 lbs (80 kg), Anil and McKinstry (66) 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 (66) 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 (63). Grandin (6) 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 that 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 that prevent amperage spiking (6,73). Both practical experience and research have shown that the aforementioned types of circuits greatly reduce petechial hemorrhages (blood spots) in carcass muscles (73,74).

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 this type of stunning, the electric current is passed from an electrode on the head to an electrode on the body. In the Velarde (75) 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 (6) 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. The author 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 (76). A single 400 volt, 1.45 amp current passed from the neck to the brisket failed to induce epileptic form changes in the brain (77). To ensure 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 epileptic form activity in the EEG of large cattle. A frequency of 50 to 60 cycles should be used unless higher frequencies are verified by either electrical or neurotransmitter measurements taken form the brain.

For all species, electrodes must be cleaned frequently to ensure 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 that may be used in the future (6).

If head-only stunning is used, the tongs must be placed so that the current passes through the brain (71,64). 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 the 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 elec-
trode 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, 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 (78). Dutch scientist Hoenderken states that pigs must be bled within 30 seconds (63), whereas Blackmore and Newhook (79) recommend that they be bled within 15 seconds, to ensure that they remain insensible throughout bleed-out. The author has observed that in some small locker plants that used a slow hoist for elevating electrically stunned pigs, proper bleed-out was not accomplished within 30 seconds.

B. Captive-Bolt Stunning

A captive-bolt stunner must be positioned on the correct position on the animal’s head (Fig. 9). 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 (7). 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 insensitivity (80,81). 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.

Figure 9 Correct positions for captive bolt stunning.
Aversive methods of restraint that 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 (12–14). 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 with a low amperage current holds a sensible animal still, by paralyzing its muscles, and does not induce epileptiform changes in the EEG (82).

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.

For cattle, the most effective position for captive-bolt placement, to induce instantaneous insensibility, is in the middle of the forehead. 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 that makes captive-bolt stunning more difficult.

Observations of cattle stunning indicate that under field conditions, penetrating captive-bolt stunners are more effective than nonpenetrating captive-bolt stunners that have a mushroom-type head; observations in many plants indicate that there is less margin for error with nonpenetrating captive-bolt stunners and the shot must be exactly on target to render the animal instantly insensible.

The use of mechanical head restraint will improve the accuracy of captive-bolt stunning, but it can increase stress if it is improperly used (83). To minimize stress, the animal should be stunned within 5 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.

**C. Carbon Dioxide Stunning**

There has been controversy about the humaneness of carbon dioxide (CO$_2$) stunning. Velarde (75) reported that, as in other countries, the use of CO$_2$ stunning has recently increased in popularity in the European Union but its acceptability on welfare grounds has been questioned by several researchers. Gregory (84) 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 (85). On the other hand, from the study of the changes occurring in the EEG patterns of pigs, Forslid (86) observed that purebred Yorkshire pigs reach insensibility before the onset of the violent motor activity. Some people who are interested in animal welfare claim that CO$_2$ 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 CO$_2$ gas to pigs. For pigs of some genetic types, use of CO$_2$ stunning is probably very humane but for other pigs it may be very stressful.

Ring (87) concluded that because pigs stunned with N$_2$ in his study, despite lower PaO$_2$ than the CO$_2$-stunned pigs, did not show any signs of restlessness, choking attacks,
collapsing, or flight reflexes for 2 minutes, stunning with CO₂ cannot be considered to be caused by hypoxia. Raj (88) found stunning pigs in argon resulted in a faster loss of consciousness than CO₂. They measured both electrocardiogram and somatosensory evoked potentials from the brain. German researchers 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 (89) 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 (86) in his work on purebred Yorkshire pigs reported that determinations of plasma cortisol, adrenaline, 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 preexposure situation.

Dutch research indicated that the excitation phase that occurs during CO₂ stunning starts prior to the onset of unconsciousness (63); this study raised the question of potential distress in pigs during the induction of CO₂ anesthesia. More recently, research by Forslid (90) 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 (Anders Forslid, Swedish Meat Research Institute, personal communication). In Yorkshire X Landrace crossbred pigs, exposure to CO₂ was less aversive than were electrical shocks (90). Aversion was measured by determining the time required to enter and reenter a CO₂ Dodman (91) and Grandin (92) observed, in a commercial slaughter plant in the United States, that white crossbred pigs (with Yorkshire breed-type characteristics) had a much milder reaction to CO₂ than black, white-striped crossbred pigs (with Hampshire breed-type characteristics).

Grandin (5,93) concluded that the effect of genetic factors on the reaction to CO₂ may make it 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 (5).

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 (93). Grandin (5) 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 (94). 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 (94) expressed concern that reactions in Halothane-positive animals may possibly be of animal welfare concern but concluded that
the use of high CO$_2$ 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 (87). It is likely that some Halothane-positive pigs were tested in the Ring (87) 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.

Human beings also vary in their reaction to CO$_2$. People who have panic attacks, which have a strong genetic basis, will react very badly to CO$_2$; the gas may induce panic attacks in these people (95,96). Neville Gregory from the Meat Research Institute in England reviewed a number of studies that indicated that most people find the smell of CO$_2$ gas to be pungent when it is breathed at a concentration of 50%.

In conclusion, CO$_2$ 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 CO$_2$ and argon gas may create an improved gas stunning system for poultry (97). It is possible that a combination of CO$_2$ and argon might make CO$_2$ stunning less stressful for genetic types of pigs that react badly to CO$_2$. 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.

One welfare advantage of CO$_2$ stunning is that CO$_2$ systems can be designed so that lining pigs up in single file races can be eliminated. In Denmark, pigs are moved into the CO$_2$ chamber in groups of five. Handling pigs in groups makes quiet handling easier. Whereas cattle and sheep are animals that will naturally walk in single file, pigs resist lining up in a single file race. Systems in which cattle and sheep are moved through single-file races can be made to work extremely well. However, pigs move more easily in small groups.

**D. Assessing Insensibility**

Only measurements taken directly from the brain in a laboratory are appropriate for assessing any change in stunning parameters. However, if an animal shows any signs of return to sensibility on a slaughter line, immediate corrective action must be taken.

To assess insensibility in a meat plant one should look at the stunned animal's head and ignore the reflexes occurring in the body (5). 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 that causes instant unconsciousness. This seizure causes rigid spasms that last for at least 30 seconds; these spasms can mask signs of sensibility such as blinking. After the stunner amperage is set correctly the animal should not be evaluated for insensibility until 30 seconds after electric stunning.

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 (5, 6, 98). 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 (99). If the tongue is hanging straight down and is limp and floppy, the animal is definitely stunned; if the tongue is stiff and curled, this is a sign of possible sensibility.

The heads of chickens or turkeys that have been stunned with electricity or gas should hang straight down after stunning. Birds that have not been properly stunned will show a strong righting reflex and raise their heads. Both mammals and birds that have been stunned with CO$_2$ 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. For all stunning methods, blinking where an open eye closes and then fully re-opens is a sign of returning to sensibility.

E. 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.
Figure 11  Head-holding device for ritual slaughter. This head holder could also be easily modified to apply electrical stunning of cattle. The head holder is mounted on a center track conveyor restrainer.

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 United States; in Europe and Canada, however, ritual slaughter is covered by humane slaughter regulations. Because ritual slaughter is exempt in the United States, 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 (100).

The latest guidelines for ritual slaughter, published by the American Meat Institute (6,55), strongly recommend the use of upright restraint devices (Figs. 10–12). 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.

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 (5,100). To determine whether cattle feel the act of having their throat cut, Grandin (5), at one plant, de-
liberately 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 (5). Invasion of the cattle’s flight zone by touching its head caused a bigger reaction (5,100) 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 (5).

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 pre-slaughter 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 (101,102). Grandin (5) 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. Cattle that fight restraint are more likely to have prolonged sensibility; gentle operation of restraint devices facilitates rapid loss of sensibility (5).

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 perform-
ing kosher slaughter in an upright restraint system indicated that under 5% of the cattle vocalized when the system was operated correctly (103). Dunn (8) 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 (8). 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 (5,28,29,59,60,100,104). 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 (100).

XII. STUNNING METHOD AND BLOOD-SPLASH

The major negative effect on meat quality of poor 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.

Lambooy and Sybesma (105) stunned pigs with 70 volt or 475 volt electricity in groups, in the shackling pen, or in a conveyor restrainer or with CO₂ stunning. They 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 (106) compared pig-handling treatments that consisted of an experimental treatment (shortened stunning time; no electric prods and overnight rest prior to stunning) to a control treatment in which electric prods were used. 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 is 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 slaughter plants by the National Pork Producers Council and the National Cattlemen’s Beef Association indicate that blood-splash is costing the pork industry almost 50 cents for every hog marketed (106,107) and is costing the beef industry about 12 cents for every slaughter steer or heifer marketed (107). In the pork industry, damage to loins and hams is costing approximately $43 million annually (106).

Sensitivity of individual animals to blood-splash differs greatly (108). Unstable weather, especially circumstances in which ambient temperatures quickly fluctuate, can make animals more sensitive to such damage. Grandin (109) found that fluctuating weather affected the efficacy of improved 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 pigs (109).

Research has demonstrated that an automatic stunning system mounted on a center track (double rail) restrainer reduced blood splash by 20% compared with a standard V-conveyor restrainer. On V-conveyor restrainers, blood-splash will increase if one side of
the conveyor runs faster than the other (76). Carbon dioxide stunning will produce less blood-splash than does the average electrical stunner (110). 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 lean 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.

Quiet handling is essential. Pigs that rear or struggle during stunning are more likely to be double stunned, which may increase blood-splashing. Blood-splash will also increase in pigs left in the restrainer during breaks. Practical experience has also shown that blood-splash will increase in a V-restrainer conveyor if one side runs faster than the other. This causes stretching of the animals' skin.

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 pig's brain to induce instantaneous unconsciousness (63). 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 hogs.

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% 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 within certain limits. There is no reason to stun hogs with 0.5 amp. An electronic system with constant amperage will generate less blood splash than will use of a voltage-regulated system at 0.5 amp. 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 2 hours; the operators should be rotated every few hours to prevent fatigue from increasing blood-splash.
There has never been a test comparing CO$_2$ stunning to electronically controlled constant amperage electrical stunning in the same plant. The test described previously, in which CO$_2$ 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 CO$_2$ stunning. The principles described above apply to both manual and automatic stunners.

**A. Quick Bleeding**

It is essential that animals are bled quickly after electric stunning. The animal should be stuck within 15 seconds after stunning. This will reduce blood-splash in all species (72,111). Bleeding very quickly reduces blood-splash because quickly lowering the blood pressure helps prevent small capillaries from bursting.

**B. 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.

**C. Resting and Handling Animals**

Practical experience in many pork slaughter plants reveals that pigs should be rested for 2 to 4 hours 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 (112) 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.

**D. 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 (113,114) showed that air in-
jection 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.

E. Ritual Slaughter

Cattle and calves slaughtered without stunning (Jewish ritual slaughter—kosher, Moslem—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 (5). 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 the 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 either pre or 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. (115), studying bobby (newborn) 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. New Zealand researchers 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 as 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.

XIII. BRUISING AND MEAT QUALITY

Rough handling is a major cause of bruising in all species. Grandin found that cattle handled quietly had half as many bruises (3). Bruises cost the U.S. beef industry $4.03 for ev-
ery fed steer or heifer marketed (116). Forty-nine percent of the fed cattle marketed in the United States have bruises (117). Bruises on cull cows that have passed through many auctions is even higher (108). Cattle that have been handled at auctions had more bruises than animals marketed directly (118,119).

Contrary to popular belief, animals can be bruised right up until the moment of bleeding (120). Cattle with horns or tipped horns had more bruises than cattle that were completely dehorned (121–124). Tipping the horns did not reduce bruising. Overloading of trucks will increase bruises but increase the incidence of downed animals (125). There is an optimal truck loading density (126). If animals are either too loose or too tight, bruising will increase. Recommended stocking truck densities for different types of animals can be found in National Institute of Animal Agriculture, Bowling Green, Kentucky, Grandin (29,104), and in Codes of Practice published by producer organizations.

A. Death Losses in Pigs

High heat combined with high humidity can be deadly to pigs. The Livestock Conservation Institute Livestock Safety Index provides an easy-to-use guideline for safe transport of pigs. When the temperature is 30 °C with a relative humidity of 50%, pigs should be transported in the early morning or at night. Lean hybrid pigs with heavy muscling are more prone to death losses than old-fashioned fatter pigs. The author has observed that death losses in pigs doubled and tripled when lean hybrids were first introduced. Growing pigs to very heavy weights (over 114 kg) increases the problem.

B. PSE in Pigs

Both scientific research and practical experience has shown that genetics is a major factor in the cause of PSE. Several studies have shown that pigs that are homozygous positive for the stress (Halothane) gene will have a greater incidence of PSE (127). Pigs that carry one gene will be intermediate in pork quality. Experience in many plants indicates that genetics contributes to 50% of the PSE, poor handling 10% to 12%, and chilling about 30%; the last 10% is caused by fluctuating weather and other factors. Resting pigs for a minimum of 1 hour prior to stunning will reduce PSE (128,129). Quiet handling in the stunning race will reduce PSE 10% to 12% according to tests conducted in several large plants. Meat quality in pigs can be degraded during the last 5 minutes in the stunning race. This is why quiet handling is so important. Pigs that get hot and overheated are more likely to have poor pork quality. Infrared measurements of high-skin temperature are correlated with quality problems (130).

C. Preventing Dark Cutters

Dark cutters cost the beef industry millions of dollars annually. The latest National Beef Quality Audit figures estimate that dark cutters cost the U.S. industry $1.36 for every fed steer marketed. In 1975, the incidence of dark cutting in fed steers was estimated at 0.5% (131). During the early to mid-nineties, dark cutting doubled to 1% according to the National Beef Quality Audit. Dark cutting meat is darker than normal and has a shorter shelf-life. Many factors contribute to dark cutting, such as fluctuating temperatures, mixing strange cattle, and hormone implant programs. Grandin (132) and Price and Tennessen (133) both report that fighting between strange cattle will increase dark cutting. When cattle are mixed, they fight to determine a new dominance hierarchy. Mixing young fed bulls can result in up to 73% dark cutters (133). Cattle breed will also affect the incidence of dark
cutting. Zebu crossbreds had fewer dark cutters compared with shorthorns (134). Observations by the author at slaughter plants have indicated that the incidence of dark cutting can be very high in cattle from certain feedlots. Dark cutters from high-incidence feedlots can run up to 30% during periods of fluctuating temperatures. The introduction of trembolone acetate implants correlates with the increase in dark cutters. Scanga (135) reported that the overuse of trembolone acetate (synthetic male hormone) implants significantly increased the incidence of dark cutters in fed steers. This study utilized the computer records of two large meat plants, and over two million cattle were studied. The Scanga (135) study verified many anecdotal observations on dark cutting. Fluctuating temperatures and extremely high temperatures also contributed to dark cutters. Ambient temperatures of over 35°C for 24 to 48 hours prior to slaughter increased dark cutters in both fed steers and heifers.

Other factors that increase dark cutters include spending the night at the slaughter plant and cattle that are extremely wild and agitated. Voisinet found that cattle that become agitated during handling had lower weight gains, more borderline dark cutters, and tougher meats (4, 136). Several studies have shown that bulls are much more susceptible to dark cutters than steers or heifers (133).

XIV. CONCLUSIONS

Improving animal welfare is both the right thing to do and it is economically advantageous. During a 25-year career, the author has observed that the single most important factor that determines how animals are treated is the attitudes of management. Good equipment makes good welfare easier, but it is useless unless it has good management to go with it.

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