Mechanical, Electrical and Anesthetic Stunning Methods for Livestock

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Abstract

A good stunning method must render an animal unable to experience pain and sensation prior to hoisting and slaughter. The three basic types of stunning methods which are classified as being humane (i.e., painless) in the United States, Europe and other foreign countries are captive bolt (penetrating and nonpenetrating), electrical, and CO$_2$ (carbon dioxide) gas anesthesia.

The physiological mechanisms of stress are the same before and after the onset of unconsciousness. The release of epinephrine as a result of stress inducers has an effect on the quality of the meat and it is therefore desirable to use a stunning method which produces a minimum of epinephrine secretion.

A literature review indicates the following stunning methods most reliably rendered the animal insensible to pain and minimized detrimental effects to forebrain. Cows, steers, heifers, calves—penetrating or nonpenetrating (where brains are being saved) captive bolt or gunshot to the forehead. Shoot behind the poll for heavy Zebu or Brahman cattle only. Market weight pigs (180-250 lb, 80—112 kg.)—electric stunning minimum of 1.25 amps. at 300 to 600 volts with 1 to 3 second application time. Sheep—penetrating captive bolt, gunshot, or electric stunning with sharp pin electrodes or electrodes soaked in brine to insure electrical contact through the wool.

Determining Unconsciousness

It is often difficult to determine whether an animal is truly unconscious and insensible to pain without special equipment. The only reliable method for measuring unconsciousness is the electroencephalogram (EEG), which records electric impulses emitted from the brain. Another useful tool, the electrocardiogram (ECG), which records electric impulses emitted from the heart, should not be used as the sole indicator of unconsciousness, since an animal can still be conscious for several seconds after the heart stops beating (Croft, 1952; Nangerone and Ken-nett, 1963; Roberts, 1954). The ECG may be used to determine an animal’s response to pain (Croft, 1952) since the cardiac pain reflex will occur in an animal which, although completely paralyzed and unable to move, is still fully conscious (Croft, 1952; Roberts, 1954; Von Mickwitz and Leach, 1977; Warrington, 1974). When a new stunning method or procedure is being tested, or an old one re-evaluated, it is recommended that the EEG be used, perhaps in conjunction with the ECG.

Reflex testing of a stunned animal is another method which can be readily implemented in the slaughter plant to detect animals which have not been properly stunned. However, reflex testing is not a definite indication that an animal is unconscious and insensible to pain since reflexes may be absent in a conscious animal.

Reflexes of the eye, conjunctiva, cornea and eyelid are the most sensitive simple tests for determining consciousness of animals stunned by penetrating and nonpenetrating captive bolt, CO$_2$, or gunshot. However, these should not be used to determine the effectiveness of electrical stunning, as electrical stimulation can cause the eyelid muscles to contract, thus masking the reflexive action (Warrington, 1974). The eye pupillary reflex to light may be used as an indicator of unconsciousness because it is not affected by electric stunning. The pupillary reflex is also the first indicator that an animal is returning to consciousness (Croft, 1952).

Indicators of Unconsciousness by Captive Bolt

It is often impossible for the captive bolt operator to test eye reflexes routinely because the animals fall down in the chute and will thus be inaccessible. Certain bodily reactions, which occur when an animal is stunned correctly, can be used instead.

When the animal falls after being shot or stunned with penetrating or nonpenetrating captive bolt, it should collapse instantly. Muscle contractions in the body which result in the curling of the tail and/or tensing of the neck before the head drops should last no longer than 3 to 5 seconds. In some instances, the entire body and neck will quiver just before the head finally rests on the floor. This is a normal reaction and is not a sign that the animal is conscious.

The ears are also a good indicator of the conscious state of the animal. If the ears do not droop and become completely relaxed within 3 to 5 seconds the animal may still be conscious.

Erratic, uncoordinated reflexive movements should not be confused with consciousness since such movements will occur even after the head has been removed. However, when the animal is discharged from the stunning pen or restrainer, the head should be completely relaxed and immobile and the ears should droop. If the ears or head respond to being poked with an electric prod the animal may be conscious.

Indicators of Unconsciousness With Electric Stunning

The only criterion for unconsciousness in electric stunning is the grand mal seizure (Hoenderken, 1978a,b; McGough and Madsen, 1964; Schwerdt, 1939; War-
If the seizure takes place the animal will definitely become unconscious. The symptoms of a grand mal epileptic seizure are similar in all mammals (Croft, 1952; Croft and Hume, 1956; Carding, 1971).

Stage 1. (Tonic Phase) The hind legs stretch out violently, the forelegs become stiff and the head bends backwards. Respiration stops. The only definite sign of unconsciousness is full extension of the back legs.

Stage 2. (Clonic Phase) Ten seconds after stunning the animal should gradually relax and make walking movements with its legs. The throat must be cut within 30 seconds to ensure that it does not recover consciousness (Hoenderken, 1978a,b).

Stage 3. If the animal is not bled, it will start to regain consciousness in 60 seconds. Consciousness can first be detected by the pupillary reflex to light. After consciousness is regained, the animal will remain paralyzed for another 30 seconds.

Carding (1971) warns that when the electro-coma technique is used (the current is applied for 14 seconds or more), the Stage 1 spasm is masked. In this technique, the current should be tested periodically by stunning several animals for 1 or 2 seconds to check for hind leg extension. In the United States, stunning times greater than 5 seconds are seldom used.

**Review of the Mechanical Stunning Methods**

There are three types of mechanical stunners: penetrating captive bolt, non-penetrating captive bolt, and gun shot. Either air pressure or a blank cartridge drives a steel bolt into the middle of the animal’s forehead in penetrating captive bolt stunning. The bolt is then automatically retracted and reset for the next animal. The length of the rod which penetrates the animal’s head varies from 2 3/8 in (6 cm) to 3 1/2 in (9 cm) [Von Mickwitz and Leach, 1977]. The nonpenetrating captive bolt stunner works in a similar fashion except the end of the rod has a wide blunt mushroom shaped head, which does not penetrate the skull. Unconsciousness in the animal is produced by impact and concussion. Both types of captive bolt stunners are available in either cartridge fired (Figure 1) or air operated (Figure 2) models. A new hydraulically activated captive bolt stunner has been developed by Hantover, Inc. (Kansas City, MO). Initial tests in a large beef slaughter plant indicate that it stuns cattle more effectively than most air operated stunners.

Many captive bolt stunners are designed so that they can be converted to either penetrating or nonpenetrating by changing rods and housings. Regular pistols and guns may also be used for stunning livestock. Special bullets are available for .22 caliber which disintegrate a short distance after they leave the muzzle of the gun, thus reducing safety hazard.

Tests on sheep and calves indicated that penetrating captive bolt stunning actually kills the animal and unconsciousness is induced instantly [Freeseeman, 1975; Cross, 1976; Von Mickwitz and Leach, 1977] Properly applied nonpenetrating captive bolt techniques will render large steers permanently unconscious. Nonpenetrating captive bolt should not be used on sheep [Von Mickwitz and Leach, 1977]. The bony ridge and wool on the sheep’s head dissipates the force of the blow (R. Kilgour and C. Steele, personal communication).

The force of the blow is very important to insure unconsciousness. The impact from either a penetrating or nonpenetrating captive bolt must be sufficient to jolt the brain inside the skull [Von Mickwitz and Leach, 1977]—mere penetration is not necessarily sufficient. It is possible to use too much force and to fracture the skull. This reduces the effectiveness of the concussion.

The instructions which accompany the stunner must be carefully followed. Most manufacturers of cartridge-type stunners supply blank cartridges with different sized powder charges to propel the bolt. It is important that the correct cartridge is used for the size and type of animal which is being stunned since the amount of powder in the cartridge determines the force of the blow delivered by the captive bolt. Air operated stunners should be adjusted by increasing or decreasing the air pressure.
Location of Stunner

An animal which fails to go down on the first stunning attempt will become more difficult to stun on each subsequent attempt (author's observation). Therefore, it is of the utmost importance that the stunner is placed on the correct location on the animal's head (Figure 3). Incorrect positioning will fail to produce unconsciousness (Von Mickwitz and Leach, 1977). Both penetrating and nonpenetrating captive bolt stunners should be placed against the animal's head. Pistols or rifles should usually be held a few inches away.

On sheep, the stunner may be placed in the frontal position as shown for cattle (Figure 3) (Blackmore 1975) or directly on the top of the head (Carding, 1971). If Brahman cattle are being stunned, the stunner should be aimed 1/2-1 in (1-2 cm) off the center of the X in the middle of the forehead, as shown in Figure 3 (author's observation). The skull of the Brahman has a bony ridge in the middle and the bolt is sometimes unable to penetrate it (C. Steele, personal communication).

The LeFiell Co. (San Francisco, CA) is experimenting with a totally new type of stunner, which will enable the slaughterer to save brains. The stunner drives a narrow 3/16 in hollow titanium shaft into the animal's forehead. Simultaneously the animal is rendered unconscious by high pressure air which passes into the brain through the shaft. Preliminary tests indicate that it may be able to stun beef animals more effectively than a nonpenetrating captive bolt.

Shooting cattle in the poll (i.e., in the hollow behind the horns) should be avoided (Von Mickwitz and Leach, 1977), especially in European cattle breeds. The only time that poll shooting should be applied in European cattle breeds is if the first shot fails to stun the bovine and it has to be shot a second time. Shooting in the poll with penetrating captive bolt is recommended, however, for heavy Zebu and Brahman cattle if the skull is extremely thick (J.C. Walsh, personal communication). The stunner must be aimed so that the brain is penetrated. If the rod merely severs the spinal cord, the animal may be paralyzed and still conscious.

Captive Bolt Pistol Types

Cartridge-fired captive bolt stunners come in models which can be held in one hand (Figure 1) or which are mounted on a long handle and held in two hands. Most plants in the United States prefer the hand held types of cartridge stunners. Air operated stunners, also available in one- or two-handed models, are heavier than cartridge fired stunners and are usually suspended from a spring-loaded balancer.

There are two basic types of triggering mechanisms. Type 1 works like a regular gun and the captive bolt fires when the trigger is pulled. Type 2 is trig-
T. Grandin—Stunning Methods for Livestock

Review Article

T. Grandin—Stunning Methods for Livestock

Review Article

tend to encourage shooting in the poll. However, where Zebu cattle have to wait until the animal's head is still and then quickly place the stunner on its head, they should be stunned when their heads first emerge from the flight zone. This is a special problem with cattle. The best technique is to develop a pen with a stanchion type head restraint.

For smaller plants handling less than 20 cattle per hour, Iowa State University experimented with a head-restraining yoke in a conventional stunning pen. This type of system may work well in a small plant where each bovine could be quietly restrained. In larger plants, attempting to yoke each animal's head in a conventional stunning pen would probably cause more bruises and excitement than simply leaving the animal loose.

A yoke type restrainer is not recommended for pigs. Marple (1977) and Overstreet et al. (1975) reported that pigs restrained in a head yoke for one minute had a low muscle pH, which is an indicator of stress.

In existing conventional stunning pens, the installation of a movable side to crowd the animal snugly against the discharge door would be a better approach. A squeeze side is especially recommended for plants handling various sized cattle. For smaller plants handling less than 20 cattle per hour, Iowa State University developed a pen with a stanchion type head restraint.

A common error is the attempt to chase the animal's head as it moves when aiming the stunner. This is a special problem with cattle. The best technique is to wait until the animal's head is still and then quickly place the stunner on its head and pull the trigger. The greatest accuracy is achieved by a motion which resembles a snake striking. The operator should never stand in front of the animal in a conventional stunning pen since the animal will become agitated and excited because its flight zone has been penetrated (Grandin, 1980a). The operator should stand slightly behind the animal's head (Figure 1), attract its attention with a clicking sound, and then reach over its head to fire the stunner.

When cattle or pigs are being stunned with a captive bolt stunner in a conveyor restrainer, they should be stunned when their heads first emerge from underneath the hold down rack (Figure 4). Otherwise, the animals may attempt to escape because the operator is inside their flight zone.

Even the most skilled stunner operator will miss once in a while. In order to avoid animal suffering, a second stunner should always be kept loaded and ready so that the animal can be immediately shot a second time. Plants which slaughter more than 50 animals per day should definitely have at least two stunners. Plants using an air operated stunner should have a cartridge fired stunner as a back-up.

**Captive Bolt Stunner Maintenance**

A stunner must be well maintained to ensure that it will deliver a lethal blow to the animal each time it is fired and to ensure that the rod retracts after every firing. For Zebu cattle, where rod sticking can be a problem, ISPA (International Society for the Protection of Animals) developed penetrating captive bolts with a penetrating tip of larger diameter than the rod (J.C. Walsh, personal communication).

Stunners can be damaged by shooting them against the side of a steel or concrete chute, or by banging them against steel or concrete to reset the rod (Von Mickwitz and Leach, 1977). If a surface is needed to push the rod back into the barrel to reset the stunner, a block of wood or piece of plastic meat-cutting board should be used. The stunner can also be damaged by not placing it squarely on the animal's head. Repeated shooting of the stunner on an angle will eventually bend the rod and diminish the hit force.

In cartridge operated stunners, a common cause of misfiring is a weakened firing pin spring resulting in insufficient force to detonate the cartridge. Captive-bolt stunners should not be fired into midair—they are designed to work against resistance.
Electric Stunning

Electric stunning is performed by passing an electric current through the animal’s brain in order to produce instant unconsciousness. If the current fails to pass through the brain the animal will be paralysed (curarized) but will still be fully conscious and able to feel pain (Cront, 1952; Hoenderken, 1978a; Roberts, 1974).

Electric stunning is an excellent method, especially for pigs, when it is used correctly. The method is clean and the application does not require a great amount of skill, although many factors can affect an animal’s sensitivity to electrical stunning. These include breed, wetness, degree of fatness, and the amount of hair or wool. In pigs, for example, the size and age can affect the voltage and amperage required to cause a grand mal seizure (Cront and Hume, 1956; Best & Donovan Co., personal communication; and Pemberton’s Inc., personal communication). Integrated circuits have recently been designed so that a constant amperage can be applied across the animal even if the resistance varies, due to moisture or spillage of the electrodes.

Voltage, Amperage and Shock Duration Requirements

Pigs—Studies to determine the voltages and amperages required to stun 180-250 lb (80-112 kg) market weight pigs indicate that with application times of 1 to 5 seconds, a minimum of 1.07 amps and 180 volts was required (Hoenderken, 1978a). Use of 1.25 amps at 300 to 600 volts produced more reliable results and unconsciousness could still be achieved even if electrode placement was slightly off. The amperage is the most important factor in producing unconsciousness. The pig must be bled within 30 seconds to insure that it is still unconscious (Hoenderken, 1978b) and in most large slaughter plants the stun to bleed interval is much shorter than 30 seconds.

A survey of European slaughter plants shows that many of the stunners had only 70 to 500 milliamps (0.07 to 0.5 amps) of current (Von Mickwitz and Leach, 1977). The average amperage varied from 70 to 150 milliamps while the voltage varied from 65 to 280 volts. The duration of application had to last an average of 13 to 26 seconds in order to be effective (Von Mickwitz and Leach, 1977). This method, using the longer application time and lower amperage, is called electro-coma. It is not recommended (Hoenderken, 1978a) because if the stunner fails to produce unconsciousness, a pig would have to withstand the shock for up to 20 seconds instead of only 1 or 3 seconds. If the electro-coma method is used, the current should not fall below 250 milliamps (0.25 amps) at 70 to 90 volts, for 14 seconds (Carding, 1971). Pigs should be watered prior to stunning but not fed for 8 hours prior to stunning because a fed pig is more resistant to the effect of the electricity (Cront, 1952; Bywater, 1967; Carding, 1974). Sheep and Calves—Specific data on voltage, amperage and application times for sheep and calves is sparse. Not only was amperage data not cited in a majority of the papers, but the EEG or the grand mal seizure was not used as the criterion for effective stunning. What data is available indicates that sheep could be effectively stunned with a current of 250 milliamps at 90 volts for 3 seconds (Hickman, 1954). Sheep should be bled within 10 seconds because they regain consciousness in 12-15 seconds (Leach, 1978).

It is not impossible to make any specific recommendations concerning voltages and amperages for calves. Carding (1971) recommends 198 watt-seconds for calves. (A watt-second = voltage x amperage x seconds.) However, there are many variations on how 198 watt-seconds can be broken down into amperage, voltage and shock duration, and the papers which were reviewed had insufficient data on amperage and assessment of unconsciousness.

Type of Electric Current

Research has been conducted to determine the type of electrical waveform to be utilized for the most effective stunning. Most standard stunners utilize a sinusoidal waveform which cycles 60 times per second.

There have been several studies to determine if changing the frequency of the electrical waveform would improve the effectiveness of stunning (Borzuta, 1971; Cronf, 1952; Corbatov et al., 1976; Hlavinka and Zelinka, 1978; Hoenderken, 1978a; Leach, 1978; Marple, 1971; Martin and van der Wal, 1978; Warrington, 1974). It has been found that unconsciousness is more effectively produced using 50 or 60 cycles AC (standard house current) instead of a high frequency 1800 Hz electric current (Hoenderken, 1978a). Higher frequencies in the range of 2000 to 3000 Hz failed to produce instant unconsciousness and may cause pain (Cront, 1952; Van der Wal, 1978).

Interest in high frequencies has been generated because it reduces the incidence of muscle hemorrhages (blood splash) in the meat (Borzuta, 1971; Marple, 1977; Warrington, 1974). In addition, high frequency stunning of pigs at 1300 Hz to 2400 Hz produces a better quality meat with a lower incidence of pale, waxy, soft pork (Corbatov et al., 1976; Marple, 1977). However, the use of high electrical frequencies is not recommended at this time, since its ability to produce instant unconsciousness has not been verified with the EEC.

Another idea that has been patented is the use of microwaves to heat a portion of the brain to 113°F (41°C) for 1-7 seconds with microwaves of 100-10,000 mega Hz (Schwartz and Wacker, 1976). It is hoped that this method, if it could be perfected, would provide the meat quality benefits of high frequency and pro-
duce painless unconsciousness. Data on the effectiveness of this method is unavailable at this time.

There has also been research to determine if changing the shape of the electrical wave form from sinusoidal to square rather than changing the frequency would have an effect (Weaver et al., 1977). Studies in humans shocked with the square wave machine at a frequency of 150 Hz resulted in reliably induced seizures, with a 50% reduction in energy (Weaver et al., 1977). Additional research is required to develop new stunning technology in the 200-500 Hz range which can provide painless stunning and optimum meat quality.

**Electrode Placement**

Correct placement of the electrodes is essential to ensure that the electricity will pass through the brain and produce unconsciousness. There are many different types of electrodes which are used, although the most common types are the bridge (Figure 5), the two pegs (Figure 6) or the tongs (Figure 7). All three types and variations of them can work well if properly used.

The bridge-type electrode is recommended for high-speed plants slaughtering 300 or more pigs per hour in a conveyor restrainer (Hoenderken, 1978a,b; W. Sybesma, personal communication). Bridge-type electrodes should have one end placed on the pig’s forehead and the other end placed either on the nape of the neck or the back (Figure 5) [W. Sybesma, personal communication]. The bridge electrode may also be effectively placed sideways on the pig: one end midway between the eye and the ear, and the other end at the side of the neck or body. The bridge electrode should never have both ends applied at the same time to the neck or the back, nor should it be applied with one end behind the ears and the other end on the neck or back. This will merely paralyze the pig and not produce unconsciousness.

Peg-type electrodes basically consist of two electrode pegs spaced 3-6 in (7.5-15 cm) apart (Figure 6) which ideally should be placed midway between the eye and the ears on each side of the head in pigs. The wider spaced electrodes are usually recommended to insure that the current passes through the brain. Since it is difficult to apply the peg electrodes in this position while the pigs are moving, most plants apply them in the hollow immediately behind the ears. This position is effective and will elicit a grand mal seizure. If they are placed too far back on the neck, unconsciousness will not be produced (Croft and Hume, 1956).

Tong-type electrodes (Figure 7) are very effective for low speed plants, specifically if no restrainer is available to hold the animal. To ensure that the current passes through the brain, tong electrodes are applied to each side of the head midway between the eye and the ear or just below the ears (Carding, 1971; Croft and Hume, 1952). The tongs must never be placed on each side of the neck, on the top of the head, or on the underside of the neck (Leach, 1978; Von Mickwitz and Leach, 1977). Placement at those locations may not render the animal unconscious. It is also advantageous to soak the electrode pads in brine after every few animals to insure a good electrical contact, especially with calves and sheep due to their thicker hair and the wool (Frazerhurst, 1975).

A pig restrainer with an automatic built-in electric stunner has been developed in Europe. The refinement of automatic stunning systems may improve the accuracy of electrode placement.

**Electric Current Path for Pigs**

Blunt electrodes which do not penetrate the skin are equally as effective as those with sharp pointed ends which penetrate the skin (Hoenderken, 1978b). In addition, wetting pigs results in more reliable stunning (Best & Donovan Co., personal communication; Hoenderken, 1978a, b) and eliminates the need to soak the electrode pads.

Since pigs are usually wetted down for stunning, the entire system must be checked to ensure that the full voltage and amperage from the stunner is passing through the pigs between the ends of the electrodes and not passing through one electrode and grounding out through the restrainer or floor. Electricity flows through the path of least resistance, and if that path is through the restrainer in-
Two peg electrode for stunning pigs. Positioning the electrode in the hollow immediately behind the ears is effective and will elicit a grand mal seizure.

Tong electrodes are effective for low speed plants, especially where no restrainer is available to secure the animal. Tong electrodes are applied to each side of the head midway between the eye and the ear or just below the ear.

Current leakage through the restrainer can be checked by connecting one lead from a volt meter to the back of the pig at least 12 in (30 cm) from the electrode and the other lead to the side of the restrainer. The meter should not indicate any current leakage.

The most commonly used electrode for sheep in the United States is the double sharp pin electrode. One pin is placed on the forehead and the other on the neck or body. The electrodes can either be mounted on two separate handles where one handle is held in each hand, or a bridge type electrode can be used.

The practice of using sharp pin electrodes in sheep has been criticized as being cruel. However, only a fraction of a second passes between the prick of the point piercing the flesh and the administration of the current. If the electrode does not make a good electrical contact, the sheep will be paralyzed instead of stunned, resulting in greater pain and stress (Leach, 1978; Kilgour, 1976, 1978). The top of the head is the least painful area to apply the first electrode. The electricity should be turned on as soon as the second electrode is placed into the body.

The pin electrodes for sheep should be hook-shaped for easier application through the wool and to restrict the depth of penetration into the animal. In plants slaughtering 100 or more sheep per hour, a conveyor restrainer should be used to hold the sheep for application of the pin electrodes; in plants slaughtering less than 100 per hour, the shackling pen should be equipped with a crowd gate so the sheep are kept tightly crowded and unable to move or jump away from the electrodes. A new bridge type electrode for sheep has been developed by Thornton Equipment (Auckland, New Zealand). When the electrodes are placed, water flows through them to help make a better contact. They must be used with great care to ensure proper contact to produce unconsciousness. Pin electrodes are more reliable.

Electric Stunning Economics, Maintenance and Safety

Electric stunning equipment is very economical to operate and easier to maintain than either captive bolt or CO2 equipment. A stunner which delivers 1 amp at 300 volts with a 2-second application time uses less than 600 watts. (Watts = amps x volts.) Even if the stunner was never turned off, it would consume less than 30¢ worth of electricity per day, based on a rate of 5¢ per kilowatt hour according to the Arizona Public Service, Phoenix, AZ.

To ensure that the desired voltage and amperage is being delivered to the animal, the stunner should be checked at least once a week with a meter while the animal is being stunned. The amperage can only be measured while the current is passing through the animal. Broken electrodes might easily result in the animals being paralyzed instead of stunned. Cords and electrodes should be checked regularly with an ohm meter. The operator should wear rubber boots and the work station should be insulated.
CO₂ Stunning

The first carbon dioxide (CO₂) gas chamber for preslaughter stunning in the United States was installed at the Hormel Packing Company (Austin, MN) in 1950 and patented by L.W. Murphy (1956). It was designed to anesthetize up to 1000 pigs per hour. This method is mainly used on pigs; however, this system is usually not practical for sheep because large quantities of CO₂ are absorbed in the wool and the gas is irritating to the animal (Glen, 1971).

In the original Hormel system the pigs pass through a single file chute through a set of swinging doors and onto a moving conveyor which is compartmentalized. After the animal is enclosed in the compartment, it is conveyed down a 30° slope into the stunner containing the CO₂. It takes about 60 seconds for the pigs to pass through the tunnel before the anesthetized animals are conveyed out of the tunnel to be bled. The Butina Engineering Firm in Denmark has developed CO₂ anesthetizing chambers which require less floor space for smaller plants. The Oval Tunnel unit (Figure 8) has a capacity of 120 to 600 pigs per hour and works on a principle similar to the Hormel system. Butina also makes a Compact Plant which can anesthetize 90 to 300 pigs per hour (Figure 9) and a Dip Lift system which can handle up to 100 pigs per hour (Figure 10). In the Compact Plant, the pig enters a “V” restrainer trap, the floor of the restrainer drops away, and the restrainer then descends into the chamber containing the CO₂ gas. Of the three Butina systems, the Compact Plant is preferred as it may be the least stressful because each pig is securely restrained and unable to jump around (Hoenderken, 1978a).

CO₂ gas. Most animals will become anesthetized within 22-45 seconds at a CO₂ concentration between 65-70% (Dodman, 1977; Van der Wal, 1971). Exposure to CO₂ at high concentrations (over 80%) or for longer periods of time (over 45 seconds) may cause the animal to become stiff and as a result, reduce bleedout (Dodman, 1977; Ratcliff, 1971). Concentrations below 55% may not render the animal unconscious (Van der Wal, 1971). The balance of atmosphere in the chamber is provided by air which brings the total oxygen content to about 7%.

FIGURE 8—Butina Oval Tunnel CO₂ system. Pigs enter the system by stepping onto a moving conveyor. Each pig is held within a compartment which is formed by upright partitions on the conveyor. The compartment then descends into the chamber and the animal is exposed to the CO₂ gas in the lower part of the chamber. The lower illustration shows one person admitting the pigs and the other shackling the pigs after they emerge.

FIGURE 9—Butina Compact Plant CO₂ system. Each pig enters a “V”-shaped compartment which conforms to the shape of the pig’s body. When the compartment is lowered, the floor drops away and the pig is secured in the “V”-shaped compartment when it descends down into the CO₂ gas. The right-hand illustration shows how pigs move through the system. This is the most humane CO₂ system because struggling and thrashing are reduced.

FIGURE 10—Butina Dip-Lift CO₂ system. Each pig enters a cage and is lowered like an elevator into the CO₂ gas and then brought back up. The pig is not restrained as in the Figure 9 “Compact” system and it is free to move or struggle.
**How Stressful is CO₂ Stunning?**

Recent research and observations of animals inside the CO₂ chamber indicate that CO₂ stunning is more stressful than either properly applied electrical or captive bolt stunning. The latter methods produce instant unconsciousness. In the CO₂ chamber there is a period of 20 to 30 seconds between entering the gas and unconsciousness (Hoenderken, 1978a).

It has been reported that entering the dark chamber and riding on the conveyor was stressful to pigs and caused them to balk (Leach, 1978, Sybesma and Groen, 1970). In order to avoid this problem, Hormel Packing Company provides lights for the chutes. Personal observation indicates that, as the pigs passed through the swinging door to the lighted chamber, they were calm and would quietly walk or lie down on the moving floor conveyor. The partitions in between each pig compartment were constructed so that an approaching pig could see another pig disappearing down the tunnel, the next pig would readily follow. Problems associated with the animals being frightened by the mechanical apparatus are discussed in Grandin (1980a, b).

There is evidence that when the animals first enter the CO₂ gas they become excited and stressed prior to the onset of unconsciousness (Dodman, 1977, Leach, 1978, Von Mickwitz and Leach, 1977). Pigs emerging from the CO₂ chamber were completely turned around, contorted and showed signs of gasping. Large white Landrace pigs appeared to react more violently than other breeds which may indicate an important variable in determining the use of CO₂ anesthesia (author's observation). Lard-type pigs may react less violently to CO₂ than modern, lean meat-type pigs which tend to be stress susceptible. The excitation phase prior to the onset of unconsciousness is approximately 10–20 seconds as determined by EEG studies (Hoenderken, 1978a, b). This phase is characterized by release of epinephrine into the blood (Collins, 1976) and a rise in blood pressure (Mullenax and Dougherty, 1963).

It has been determined that animals are definitely stressed by the period of excitation induced by CO₂, but does this excitation cause pain? Several researchers have attempted to answer, but unfortunately the question is still unresolved (Bloomquist, 1957, Canton, 1977, Hoenderken, 1978a, b; Leach, 1978, Mullenax and Dougherty, 1963, 1964, Van der Wal, 1971). Although these studies produced no truly clear-cut evidence of pain, it is known that CO₂ can be irritating to the respiratory tract in both humans and nonhumans (Van der Wal, 1971; Glen, 1971, Glen and Scott, 1973; La Verne, 1973; MacArthur, 1976). Although, while humans can be anesthetized with CO₂ without discomfort (Olson, 1978; Van der Wal, 1971), animals may react differently to CO₂. Humidification of the CO₂ chamber with easy-to-install, inexpensive water foggers and warming of the gas itself could significantly reduce the stress associated with CO₂ inhalation. Another possible method of reducing the stressfulness of CO₂ is to first introduce the pig into 30% CO₂ and 70% air and then increase the mixture to 68-70% CO₂ and 30–32% air (Wernberg, 1978).

**Economics and Maintenance of CO₂ Chamber**

A CO₂ chamber is the most expensive type of stunning equipment to install initially. A large system such as the Hormel tunnel which can handle over 600 pigs per hour costs $100,000 to $175,000 to install today. Butina Engineering in Denmark manufactures smaller units which vary from $25,000 to $100,000 including installation costs. Installation of CO₂ equipment in existing plants would require structural modifications and rearrangement of holding pens and chutes. Large pork slaughter plants in the United States calculated that, in 1979, CO₂ cost 5-6¢ per animal for the gas. CO₂ is supplied to the chamber by either cylinders of compressed gas or dry ice (solid CO₂). The Hormel chamber holds a three day supply of dry ice (National Provisioner, 1956). Maintenance of the correct concentration of CO₂ requires at least daily checks. Ideally, a continuously recording CO₂ meter should be installed.

For a CO₂ chamber are much higher than for either electric or captive bolt systems. Not only do conveyor systems or lift systems have many moving parts which require constant care and replacement, but thrashing pigs may also break the partitions and the conveyors. A CO₂ chamber will remove one or two people from the processing line, but it may add an additional person in the maintenance department to repair the equipment and monitor the CO₂ level.

**Stress, Meat Quality and Stunning Technique**

In order for any stunning method to be painless, it must either induce unconsciousness instantly, or induce unconsciousness with minimum stress prior to the onset of unconsciousness. Any method used to stun or kill an animal will increase the secretion of epinephrine (adrenaline) and other catecholamines (Althen, et al., 1977; Pearson, et al., 1977). The secretion is triggered by the insult to the brain from the concussion, electricity or CO₂ gas.

Due to this fact some researchers have stated that stunning an animal is more stressful than cutting the animal's throat without stunning. The epinephrine levels are higher after stunning than after cutting the throat without stunning (Althen et al., 1977, Kilgour, personal communication). From a purely physiological standpoint, the stunned animal is more highly stressed. Properly applied stunning, however, reduces pain and discomfort to the animal because it is unconscious either before or simultaneously with the output of epinephrine and other catecholamines. It is of the utmost importance, therefore, that unconsciousness is produced by the stunning method applied.

**Conclusions and Recommendations**

The stunning method used should suit both the type of plant and the type of animal and should produce unconsciousness rapidly and without stress prior to the onset of unconsciousness. Stressful procedures are not only questionable from a humane point of view, but they can also affect the quality of the meat. Table 1 summarizes the various recommended techniques for the different types and grades of animals.

For electric stunning, the minimum power requirements for pigs are 1.25 amps at 180 volts for one to five seconds (Hoenderken, 1978a, b). Amperage readings should be taken during the actual stunning. The shortest application time which produces a grand mal seizure is recommended and the best electrode for high speed plants is the bridge design. The pigs should be wetted prior to stunning.
TABLE I—Stunning Recommendations

<table>
<thead>
<tr>
<th>Type of Animal</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulls</td>
<td>Penetrating captive bolt or gun shot to forehead (cartridge-fired stunners require heavy charges).</td>
</tr>
<tr>
<td>Cows, steers, heifers</td>
<td>Penetrating or nonpenetrating captive bolt (where brains are being saved), or gun shot to forehead. Shoot behind the poll only for heavy Zebu or Brahman cattle.</td>
</tr>
<tr>
<td>Calves</td>
<td>Penetrating or nonpenetrating captive bolt, or gun shot to forehead.</td>
</tr>
<tr>
<td>Sows and boars</td>
<td>Penetrating or nonpenetrating captive bolt, or gun shot to forehead, or electric stunning.</td>
</tr>
<tr>
<td>Market-weight pigs (180-250 lb; 80-112 kg)</td>
<td>Electrical stunning. (Captive bolt has detrimental effect on meat quality.) Minimum of 1.25 amps at 300-600 volts with 1-3 seconds application time with blunt electrodes.</td>
</tr>
<tr>
<td>Sheep</td>
<td>Penetrating captive bolt or gun shot. Nonpenetrating captive bolt must not be used. In electric stunning, use sharp pin electrodes or electrodes soaked in brine to assure a good electrical contact through the wool. Sheep must be bled within 10 seconds, otherwise they will regain consciousness.</td>
</tr>
</tbody>
</table>

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