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REVIEW ARTICLE

The Effect of Stress on Livestock and Meat Quality Prior to and During Slaughter

Temple Grandin*

Abstract

The effects of stress on cattle, pigs and sheep prior to slaughter are reviewed. Long-term preslaughter stress, such as fighting, cold weather, fasting and transit, which occurs 12 to 48 hours prior to slaughter depletes muscle glycogen, resulting in meat which has a higher pH, darker color, and is drier. Short-term acute stress, such as excitement or fighting immediately prior to slaughter, produced lactic acid from the breakdown of glycogen. This results in meat which has a lower pH, lighter color, reduced water binding capacity, and is possibly tougher. Psychological stressors, such as excitement and fighting, will often have a more detrimental effect on meat quality than physical stressors, such as fasting or cold weather. Fighting caused by mixing strange animals together is a major cause of dark cutters in cattle and deaths in stress susceptible pigs. The physiology, causes and prevention of the porcine stress syndrome and dark cutters, is reviewed. Methods for detecting genetically stress susceptible breeding stock are reviewed. The effects of stunning method on meat quality are also covered.

Introduction

Hans Selye (1973) defined stress as a nonspecific response of the body to a demand made on it. Stressors tend to displace bodily states from the resting state (Stott, 1978), but not all stress is bad. Selye's General Adaptation Syndrome involves two stages—the alarm reaction during which the autonomic nervous system is activated and glucocorticoids and epinephrine are released into the bloodstream and long-term adaptation. The discussion in this paper will be limited to the 48-hour period prior to slaughter (the alarm reaction). Long-term adaptation covering weeks and months involves physiological changes which are beyond the scope of this paper.

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The intensity of an animal's reaction to specific stressors depends on many factors, including degree of tameness and adaptation to the climate. An animal which is accustomed to being handled is likely to be less severely stressed by handling than an animal which has had no experience with people. The basic hormonal mechanisms underlying stress include the secretion of epinephrine, activating the animal for the classic "fight or flight" response, and the secretion of glucocorticoids. Glucocorticoids are released later and help to maintain energy supplies and to resist the stress (DiGiusto *et al.*, 1971).

Stress Measurement

Questions such as "How stressed is an animal?" and "What level of stress is caused by husbandry practices?" are difficult to answer. Superficially, the simplest method of measuring acute stress is comparing baseline levels for heart and breathing rate and body temperature with those obtained under stress conditions, but these parameters are complicated by physical activity. Recent developments include the use of radio-telemetry devices to record these basic parameters in order to avoid contamination from handling stressors (Stermer *et al.*, 1978; G.H. Stott, personal communication). Blood catecholamines and glucocorticoids have also been used to determine how stressed an animal is since these hormones are involved in the body's reaction and adaptation to stress.

The use of catecholamines and glucocorticoids as measures of stress is accurate only when viewed in relation to the entire animal and its environment. Kilgour (1978) considers that epinephrine levels are the most sensitive indicators of an animal's response to acute stressors such as fear or excitement caused by handling methods in the slaughter yards or stunning pen. Stott (1978) has stated that a series of measurements must be conducted if blood levels of either epinephrine or the glucocorticoids are to be used as meaningful indicators of an animal's reaction to stress.

Ray *et al.* (1972) and Willet and Erb (1972) have demonstrated that glucocorticoid levels vary widely from one animal to another. In studies conducted by Ray *et al.* (1972), the glucocorticoid levels evoked by restraint varied from 3.8 to 41.3 ng/ml. Furthermore, different breeds of animals react differently to acute stress, with Pietrain and Landrace pigs and Guernsey cows being particularly susceptible (Addis, 1976; Moreton, 1976; Moss and Robb, 1978).

The time and method of obtaining the blood sample for testing is very important. Both epinephrine and the glucocorticoids are cleared from the blood shortly after they are released. Glucocorticoid levels also vary during the day according to natural diurnal rhythms (Perry, 1973). The stress researcher must also be aware of the differences between species. Kilgour and DeLangen (1970) have reported a delay of 30-40 min between the onset of the stressor and the maximum output of glucocorticoids in sheep. In cattle, glucocorticoid levels are substantially above baseline levels 10 min. after the animal has been handled in a squeeze chute (Ray *et al.*, 1972). Certain pigs afflicted with inherited stress susceptibility have been reported to have lower levels of glucocorticoids than normal animals after both groups are stressed by exercise (Ball *et al.*, 1973).

Meat quality variables are also indicators of stress, but when assessing muscle pH, color, or meat tenderness, it is important to remember that these

parameters vary according to the part of the carcass from which the sample is obtained (Shorthouse, 1978). A terminal stress index has been developed which includes meat quality parameters, temperature, breathing rate and heart rate (Westervelt *et al.*,1976). When this was used to determine the amount of stress placed on an animal by various methods of restraint and slaughter, it was found that sheep shackled live were under greater stress than sheep restrained in an upright position.

Another possible parameter for measurement of stress in slaughter plants is the extent of heart rigor. Thornton (1971) found that cattle slaughtered in the morning had a lower incidence of heart rigor in the post mortem examination than animals killed later in the day therefore probably under greater stress. If this parameter of heart rigor can be verified as a measure of the amount of stress endured by the animal in the slaughter plant, it would be a simple and objective measure for the inspector.

Stress Factors

Fighting

When strange animals are mixed together they will fight to determine the new social hierarchy. Fighting is the major cause of dark cutters in cattle (Grandin, 1978; Moreton, 1976; Tennessen and Price, 1980) and the major cause of death losses in stress susceptible pigs (Topel *et al.*, 1968).

The cattle which were "dark cutters" were often either the lightest or the heaviest animals in the pen (Grandin, 1978). This indicates that social order is related to stress since the heavier animals are usually dominant. The higher incidence of dark cutters in lighter weight cattle is probably due to aggressive small animals which continued to fight a losing battle with larger animals. The study also indicated that the shape and size of the pens may have been a factor. The animals were in a large pen and were observed running at each other and butting at high rates of speeds. In most instances where the dark cutters were the heavier animals, the activity level in the pen was high and dominant animals expended a lot of energy. In the group where the dark cutters were the lighter weight cattle, observations indicated that the submissive lighter cattle had difficulty avoiding the dominant animals in the small (17.6 sq ft per animal) crowded pen. More research is needed to determine the optimal space requirement.

Some interesting studies with mice provide insight into the effect fighting has on epinephrine and glucocorticoid secretion. Animals which are low in the social order will often show the most signs of stress (Bareham, 1975). In mice, the glucocorticoid levels are lower in dominant animals than in subordinate ones (mice which had lost fights) [Louch and Higginbotham, 1967]. A similar finding was reported by Hucklebridge *et al.*, (1973) for epinephrine levels. Mice which had fought victories had no increase in plasma epinephrine, but mice which had lost fights had elevated levels. The elevation of epinephrine tended to be even greater in defeated mice which continued to fight back. Simply exposing a mouse to a trained fighter would raise the glucocorticoid levels even though the exposure did not involve an attack (Louch and Higginbotham, 1967). This is not true for epinephrine (Hucklebridge and Nowell, 1974) where the levels rose only during an attack.

Strange Environments and Physiological Stress

Psychological stressors such as fighting and excitement are often more stressful than physical stressors such as lack of feed, excessive physical exertion or inclement weather (Ashmore, 1973; Grandin, 1978; Hedrick, 1965). In sheep being bitten by a dog caused a greater increase in cortisol levels than being chased by the dog (Kilgour and DeLangen, 1970). Isolation and the sounds of anxious bleating were highly stressful to sheep (Lankin and Naumenko, 1979). Sudden loud noises, barking dogs and commotion will elevate thyroid epinephrine and glucocorticoid levels in sheep (Falconer and Hetzel, 1964; Pearson *et al.* 1977). A pig's heart rate will keep increasing if it is repeatedly prodded with an electric prod (Van Putten and Elshof, 1978). Unfamiliar environments are one of the most stressful aspects of preslaughter handling procedures. DiGiusto *et al.* (1971) state that "Increased epinephrine secretion seems to occur in states of anxiety or in threatening situations of an uncertain and unpredictable nature." It was reported that sheep which had been grazed on pasture would respond with a higher output of glucocorticoids when transported by truck than sheep which had been kept in close contact with people (Reid and Mills, 1962) and Hails (1978) reported that calves lost less weight the second time they were transported. At the slaughter plant, pigs held (acclimatized) in the slaughter plant yards overnight had lower levels of cortisol and thyroxine than pigs slaughtered within two to four hours of arrival (Moss and Robb, 1978). Similar results were obtained using another indicator of stress — ascorbic acid content in pig adrenal glands (Warriss, 1979).

It has been suggested that animals could be prepared to accept irregularity in management (Reid and Mills, 1962) or could be preconditioned to handling stresses (Kilgour, 1976). For example, pigs trained to certain handling procedures had better meat quality than untrained pigs (Luyerink and Van Baal, 1969). In a large feedlot, it would be impractical and uneconomical to precondition cattle to handling procedures in the slaughter yard, but it might be suitable for young feeder calves. Also, confinement swine are difficult to handle because they are not accustomed to walking and some exercise during feeding periods might be beneficial. Providing music in the feedlot corrals and in the slaughter areas might also help since the sound would be familiar.

Genetics

Stress susceptibility is an inherent trait in both pigs and cattle (Addis, 1976). Pietrain pigs have an incidence of 80% stress susceptibility as measured by the Halothane test, but Minnesota Number 1, a very stress resistance breed, have no reaction to the Halothane test (Addis, 1976). Moreton (1976) has reported that the incidence of dark cutters in Guernsey cows can be as high as 50% but Grandin (1978) reported that breed did not have any effect on the incidence of dark cutters in comparing cross breed beef cattle with English purebred beef cattle. Lawrie (1958) was one of the first researchers to suggest that dark cutting in cattle was related to a genetic susceptibility to stress. This idea was further supported by Ashmore *et al.* (1973) who reported that double-muscled cattle had a greater incidence of dark cutters. Double-muscled cattle could not withstand the strenuous exercise tolerated by normal cattle (Holmes *et al.*, 1973). Both double-muscled cattle and stress susceptible pigs have larger muscle fibers (Topel, 1979).

At the present time, dark cutting in beef is not as serious a problem as PSS

(porcine stress syndrome) and PSE meat in pigs. The incidence of PSE meat in pigs in the United States is 20% (J. Marchello, personal communication) while the incidence of dark cutters in cattle is 0.5% (Epley, 1975). However, problems of stress susceptibility could increase in cattle if double-muscled cattle are bred (Topel, 1979). Bouton *et al.* (1978), however, reports that it is possible to get the advantages of increased muscling without stress-associated problems through careful cross-breeding.The elimination of genetic stress susceptibility traits would not eliminate the need for gentle handling since even "normal" animals can produce dark or PSE meat.

Meat Quality and Stress

Energy Stores, Metabolism and Color

In cattle, sheep and pigs, a high pH will result in a darker piece of meat and a low pH will result in a lighter piece of meat. This applies to both normal and stress susceptible animals. The pH is affected in part by the breakdown of glycogen to lactic acid (in an energy producing metabolic pathway) and the rate of glycogen metabolism is affected by immediate and long-term stress and by individual differences between animals. Any type of physical stress can result in depletion of glycogen stores while psychological stressors result in rapid glycogen catabolism triggered by epinephrine output. The pH rises when the glycogen stores become depleted from a more prolonged stress and lactic acid can no longer be produced. In order to produce dark cutting cattle, the animals must be under prolonged stress of more than eight hours (Hedrick, 1978), while light meat is produced by glycogen breakdown just prior to slaughter. Lactic acid produced from glycogen breakdown is important in determining the final pH of the meat. The rate at which lactic acid is removed from the muscle appears to be reduced in pigs with inherited stress susceptibility (Ball *et al.* 1973; Topel, 1979).

Pigs which have been on a long trip in a truck will have lower glycogen levels than rested pigs (Lewis *et al.,* 1963) and Barton (1971) has reported that pigs hauled for a short distance had more PSE meat than pigs hauled for a long distance. However, the long haul pigs would probably suffer from greater shrinkage and death losses and the prolonged stress may even cause a dark cutter condition called DFD (Dark, Firm, Dry) which is undesirable (Kaufman *et al.,* 1978). Recent studies indicating that the incidence of PSE meat can be reduced by resting pigs for 6-8 hours prior to slaughter (Lengerken *et al.,* 1977; Stein, 1978) appear to contradict Barton's (1971) results. This contradiction might be explained by the problems of comparing studies with conflicting variables such as transport time, amount of fighting and the stockyard design.

In addition, Topel (1979) reports that differences in the way the animals are handled can affect meat color. For example, stress susceptible animals which are mildly stressed for 12—15 hrs will have dark, firm meat. If these same animals are stressed mildly for 7—8 hrs, they will have normal meat. Therefore, the variables which must be compared between different studies include sex, breed, weight, weather conditions, length of transport time, resting time prior to slaughter, number of animals in each pen, shape of pen, stunning method, access to feed and water and mixing of strange animals.

The longer the animals are in transit, the greater the tendency to have a high

muscle pH and dark meat (Hails, 1978). This is true for all species and is in agreement with Gallwey and Tarrant (1978) who found that pigs which had come through auction markets had a higher incidence of DFD meat than pigs transported directly from the farm. Other recent studies indicate that pigs which are slaughtered either upon arrival or shortly afterwards had a lower muscle pH and more PSE meat than pigs held in the stockyard overnight (Moss and Robb, 1978; Skjerheim, 1978).

By feeding sugar to pigs and cattle, the incidence of DFD meat and the number of dark cutters in fatigued animals can be reduced (Gallwey and Tarrant, 1978). Topel (1979) states that feeding pigs sugar water after arrival at the plant improves dressing percentages. Shasta Beverage Corporation is experimenting with an isotonic solution for animals in slaughter yards. Tests indicate that the dressing percentage is improved by 0.5-2% and dark cutting is reduced.

Stress immediately prior to slaughter usually decreases pH and increases the incidence of PSE meat. Epinephrine injections 5 min prior to slaughter increased the incidence of PSE meat (Althen *et al.* 1979). Several studies indicate that pigs which are held and fed prior to slaughter have more PSE meat than animals which are transported to the plant and slaughtered immediately (Aherne *et al.*, 1979; Danish Meat Research Institute, 1978). The pigs in both studies would have had high levels of muscle glycogen and the slightest stress would trigger glycogen breakdown and a drop in muscle pH. None of the fed and lightly stressed pigs in these studies had DFD meat with a high pH. These studies indicate a pattern of long-term stress darkening the meat and short-term, acute stress lightening the meat.

Tenderness

Excitement and stress immediately prior to slaughter usually make beef, lamb and veal tougher. The stress of shackling and hoisting live calves or sheep decreased the tenderness of the meat, while restraining the animal in an upright device produced a more uniform meat product (Westervelt *et al.*, 1976).

Other psychological and physical stressors which can reduce meat quality include high temperature, excitement and frequent use of electric prods. For example, pigs driven to the stunning area with leather slappers had fewer blood-splashed hams than those driven with electric prods (Calkins *et al.*, 1980). Also, steers prodded with electric prods every 20 min for 24 hrs prior to slaughter had tougher ribeyes (prime rib) and the flavor of the meat was decreased (Lewis *et al.*, 1962). The meat from rested lambs is more tender (Watt, 1968) and pigs subjected to 114°F for 20-60 min prior to slaughter had tougher meat than controls (Hedrick, 1965). Heat stress and struggling before and during slaughter toughened the meat of turkeys (Froning *et al.*, 1978).

Epinephrine has been implicated as a factor affecting tenderness and sheep injected with epinephrine five minutes prior to slaughter were slightly tougher than controls (Pearson *et al.*, 1973). However, electrical stunning triggers epinephrine release (Grandin, 1980) and yet it has a tenderizing effect on meat (Lee *et al.*, 1979).

During the last two or three years many beef slaughter plants have installed a device to improve meat tenderness. After the hide is removed an electrical current is passed through the skinned carcass. This electrical tenderizing process

was first developed by Harsham and Deatherage (1951). Smith *et al.*, (1977), Grusby *et al.* (1976) and Savell *et al* (1977) did much of the research needed to perfect the process. The equipment is now commercially available and it is being installed in many plants all over the United States and other countries.

As the electrical tenderizing device becomes more popular, keeping pre-slaughter stress and excitement to a minimum will become more important. Sorinmade *et al.* (1978) found that the electrical tenderizing device would not improve the palatability of beef from an animal which had been stressed prior to slaughter. The cattle used in this study were stressed by poking them with an electric prod for 10 min every 3 hrs for 15 hr and then continuously for 30 min immediately prior to stunning. They were also deprived of feed for 48 hrs. Savell *et al.* (1978) reported that electrical tenderization of the carcass can help to reduce the incidence of dark cutters because it brightens the color of the meat. However, the study by Sorinmade *et al.* (1978) shows that stress and especially stress immediately prior to slaughter reduces tenderness.

Recent studies conducted by Parrish (1978) indicate that calcium plays a major role in making meat tender. Calcium interacts with a substance called calcium activating factor (CAF) to aid the breakdown of muscle myofibrils and this fragmentation is an important element in tenderization.

There is evidence that stressful conditions cause calcium in the body to be transferred from the blood into the fatty tissue in sheep (Moseley and Axford, 1973). Plasma calcium levels declined significantly within 30-60 min after injections of epinephrine or minor surgery. The decline in plasma calcium could possibly reduce the amount of calcium which would be available in the muscle. This may be part of the process which tends to make meat tougher when an animal is highly stressed shortly prior to slaughter. Faulty calcium metabolism in the muscle is also associated with the porcine stress syndrome (Topel, 1979).

Dark Cutting in Cattle

Outline: Dark cutting beef describes the condition in which the meat has a darker color than normal and a higher pH. In severe cases the meat may have a gummy texture and a shorter shelf life. Surveys indicate that the consumer prefers beef with a bright red color although the flavor may be less desirable (Hedrick, 1965). Another problem is that dark cutting beef is likely to turn an ugly greenish color when aged in plastic vacuum bags (Gill and Newton, 1979; Moreton and Perry, 1975). Packaging cuts of meat in evacuated plastic bags will eventually replace the sale of whole beef sides from the slaughter plant because it is more efficient. The common name for the process is "boxed beef."

In fed steers, the overall industry average for dark cutting carcasses in the U.S. is 0.5% (Epley, 1975). In England, 1-2% of the steers are dark cutters and 8-10% of the young bulls will cut dark (Moreton and Perry, 1975). Dark cutting will usually cause a steer or fed heifer to be discounted one whole quality grade but is not as serious as PSE meat in pigs.

A dark cutter is usually discounted $12-$36 per animal depending on the market. When hamburger is in high demand or beef supplies are short the price differential between good and choice carcasses narrows as a higher and higher percentage of the meat is used for hamburger. In 1977 and early 1978, losses from dark cutters averaged $30 per head but figures from January 1979 indicate only

$12 loss per animal due to the large demand for hamburger and tight cattle supplies (*National Provisioner,* Daily Market News Service).

The beef packing industry loses nearly $3 million annually from dark cutting beef. This is based on USDA figures of 28 million steers and heifers being slaughtered in 1976 and 1977, and a price differential of $21 between choice and good grade.

Dark cutting can cause tremendous losses for certain types of plants (specializing in choice carcasses or boned beef), or plants which run into a dark cutting epidemic. Plants which specialize in manufacturing hamburger or lean beef suffer no economic losses from dark cutters. One plant can have zero dark cutters and another plant can have 30% dark cutters in one day (Moreton and Perry, 1975). There have been reports of truck loads with 50% dark cutters. A single dark cutter episode involving 100 steers can cost $1,200-$3,000 depending on the market. Many of these sporadic dark cutter outbreaks can be traced back to sudden changes in temperature and/or repeated mixing of strange animals.

Causes: Hedrick (1978) states that the condition is caused by prolonged stress leading to depletion of muscle glycogen stores. Epinephrine accelerates the breakdown of glycogen (Ashmore *et al.,* 1973; Bouton *et al.,* 1974; Lawrie, 1958) and dark cutting can be produced experimentally by giving cattle or sheep injections of epinephrine 24-48 hours prior to slaughter.

Many studies have been conducted to determine the effect of various physical and environmental stresses on the incidence of dark cutters. Most of the studies indicate that feed deprivation alone is not a sufficient stress to cause dark cutting (Ashmore *et al.* 1973) but a combination of stresses such as lack of feed, excessive exercise or sudden changes in temperature can increase the incidence of dark cutting (Ashmore *et al.,* 1973; Lawrie, 1958; Ramsbottom *et al.,* 1949). Cold weather and chilling caused by wind can increase the incidence of dark cutting and there tend to be more dark cutters in the fall when the temperatures fluctuate widely (Epley, 1975; Moreton, 1976; Ramsbottom *et al.,* 1949). There have also been reports from slaughter plants that there is an increased incidence of PSE meat in pigs in the fall. Cold weather increases both glucocorticoid and epinephrine secretion (Hensel, 1968; Willet and Erb, 1972), and fluctuating temperatures cause pigs to secrete more ACTH from the pituitary (Marpel *et al.,* 1974). In addition, D. Ames (personal communication) found that 90 db noise played in the slaughter plant holding pens darkened the meat. In both cattle and sheep, 100 db white noise and intermittant sounds darkened muscles (Kropf *et al.,* 1973). Running cattle for over a mile prior to slaughter did not cause dark cutters (Ramsbottom *et al.,* 1949). Fasting steers for 31 hrs prior to slaughter and then exercising them for 5 hrs caused dark cutters (Romans *et al.,* 1974). However, the steers were forced to run by prodding them with an electric prod and undoubtedly these animals were under more psychological stress than tame steers which ran without being prodded. Several hours prolonged stress from an electric prod can darken meat (Lewis *et al.,* 1962).

The major cause of dark cutters is the mixing of strange animals prior to slaughter. Both Moreton (1976) and Grandin (1978) report that there are fewer dark cutters when the animals are slaughtered on arrival at the plant. Tennessen and Price (1980) conducted studies in Canada which indicate that the mixing of

strange bulls overnight in the slaughter plant stockyard increased the incidence of dark cutters. However, the incidence of dark cutters was very low if the young bulls were kept with their feedlot penmates. Tables 1 and 2 outline the results of continuing studies by the author on dark cutters conducted with 4H and FFA project steers. These animals are raised individually and fight vigorously when mixed and dark cutter incidence can be very high. Animals spending the night at the plant had more dark cutters. There appears to be a critical period of 24-48 hours prior to slaughter where mixing and regrouping of steers is especially detrimental. The incidence of dark cutters was correlated with the number of times the animals were regrouped and repenned and the time elapsed between group penning for shipment and slaughter.

Prevention: One of the reasons the incidence of dark cutters is lower in the U.S. (0.5%)*[Epley, 1975]* than in England (8-10%)*[Moreton and Perry, 1975]* is that the majority of the fed steers and heifers are handled in large homogenous groups and not mixed with strange animals. In most instances the animals go to slaughter with pen mates they have been with for months. In England, animals are handled in smaller groups and a higher percentage of bulls are slaughtered. Furthermore, the regulations require that horned animals must always be separated from polled (hornless) animals in the slaughter plant holding pens (Lawton, 1971). This is an example of a law which in many instances can cause more stress. If a group of cattle which has been fed together for months is disrupted by sorting in the slaughter plant stockyards to remove the horned animals from the group, they are likely to become more stressed than if they were left alone. Obviously, it is not advisable from a bruise standpoint to mix a truckload of polled cattle with a truckload of horned animals, but groups which arrive mixed should be left alone, as long as they are quiet. If a pen of cattle has considerable butting and riding activity, it is advisable to sort out the extremely aggressive animals. In one pen of cattle studied by the author, an aggressive animal caused the entire pen to be more active than those in the adjacent pens. This pen had more dark cutters and the dominant (alpha) animal turned out to be a dark cutter.

Data in Tables 1 and 2 indicate that mixing strange steers together only once would usually not cause dark cutters if the animals were slaughtered within 24 hrs after mixing. The data also indicate that if strange steers were mixed together and then re-sorted so that their social hierarcy was disturbed *two* or *three* times within 48 hrs prior to slaughter the incidence of dark cutters rose sharply. In Table 1, one group of steers was regrouped twice, spent the first night in the shipping pen and the next night in the slaughter plant pens. Normally 4H and FFA project steers handled in this manner will have a high percentage of dark cutters because they fight when mixed. This group had no dark cutters. They had been placed in a long narrow pen instead of a square pen, but more research must be done to check the effect of pen shape on dark cutter incidence.

Dark cutting in cattle which spend the night in the slaughter plant stockyards can be practically eliminated in steers if the same group of animals are kept together in the stockyards. If bulls or young bullocks are being slaughtered they should be slaughtered as soon after arrival as possible. It is recommended that steers, cows or heifers be kept overnight in the pens for the next day's operation and that bulls and bullocks be slaughtered promptly. If strange bulls have to

TABLE 1. Handling Procedures which Reduced the Incidence of Dark Cutters in Individually Raised 4-H and FFA Project Steers

Group†	# Head	# Dark	% Dark	Nights in Fairground Shipping Pen	Nights at Plant	Regrouping Frequency	Comments
Method A (3 groups)	80	0	0	0	0	0	Loaded on the truck from the individual stall. No group penning at the Fairground. Slaughtered upon arrival at the plant.
Method B (3 groups)	64	0	0	0	1	1	Loaded on the truck from the individual stall. No group penning at the Fairground. Group penned for one night at the plant.
Method C (2 groups)	45	0	0	1	0	1	Group penned for one night at the Fairgrounds. Slaughtered upon arrival at the plant.
Method D (1 group)	17	0	0	1	1	2	Held in a long narrow pen at the Fairgrounds which may have reduced stress. These were the only steers grouped one night at the Fairgrounds and one night at the plant which had zero dark cutters.
Method E (2 groups)	84	3	3.5	2	0	1	Group penned for two nights at the Fairgrounds and slaughtered upon arrival. Stress reduced by only one regrouping.
TOTAL	**290**	**3**	**1%**				

†Groups: 15 To 58 head, average group size 15 to 30 head. Every time strange cattle are mixed together, they fight to establish a new social order. Reducing the number of times the animals were regrouped and mixed with strange cattle and the time elapsed between group penning and slaughter reduced the incidence of dark cutters. These observations were conducted under steer show conditions and no attempt was made to influence how the cattle were handled. Data collection was started when the 4H and FFA members placed their steer in the group shipping pens at the fairgrounds. This was counted as the first regrouping. Repenning at the slaughter plant was counted as the second regrouping.

TABLE 2. Handling Procedures which Increased the Incidence of Dark Cutters in 4-H and FFA Project Steers.

Group†	# Head	# Dark	% Dark	Nights in Fairground Shipping Pen	Nights at Plant	Regrouping Frequency	Comments
Method F (3 groups)	76	10	13	1	1	2	Group penned for one night at both the Fairgrounds and at the packing plant.
Method G (3 groups)	109	19	17	1	1	3	Group penned for one night at both the Fairgrounds and packing plant. Re-sorted at either the Fairground or packing plant group pens.
Method H‡ (1 group)	20	2	10	3	0	3	Group penned 3 nights at the Fairgrounds and re-sorted at the Fairgrounds. Slaughtered 3 hours after arrival at the plant.
Method I (1 group)	9	1	11	3	0	1	Group penned 3 nights at the Fairgrounds. Grouped together in a single pen at the packing plant. Half were slaughtered one day and half the next day.
Method J (1 group)	9	1	11	3	1	2	
TOTAL	**223**	**33**	**14.7%**				

† GROUPS: 9 to 59 head. Average group size 15 to 30 head.

‡ GROUP H was placed in one 16 x 32 foot (4.9m x 9.7m) pen as a group for the first night at the Fairgrounds. The following morning half of the animals were placed in two 16' x 16' pens. The animals remained in three different Fairgrounds' pens for two more nights. When they were taken to slaughter, they were regrouped in one pen at the packing plant. The two dark cutters were in the same fairground pen which contained 10 cattle. One of the dark cutters was a dominant animal with a horn. The rest of the cattle were polled. The pen which contained the two dark cutters had more activity than the other two pens. Data collection was started when the 4H and FFA members placed their steers in the group shipping pens at the fairgrounds. This was counted as the first regrouping. Repenning at the slaughter plant was counted as the second regrouping. If the steers were re-sorted or switched into different pens, it was counted as an additional regrouping.

be mixed before shipment to slaughter, then they should be mixed a week in advance (Moreton and Perry, 1975). Loads of cattle which have been shipped for long distances or through bad weather, should be allowed to rest for one or two hours and then slaughtered.

Stress Susceptibility in Pigs

Porcine Stress Syndrome (PSS) is an inherited condition which costs the U.S. industry $250 million annually in lowered meat quality—a condition called PSE meat (Pale, Soft, Exudative)—and death losses (Williams, 1977). PSS is one of the major causes of death during transit, susceptible pigs having ten times the death rate of normal pigs (Eikelenboom *et al.,* 1978). Prior to the advent of new types of meat pigs, stress susceptibility was not much of a problem in the U.S. But in 1971, a survey indicated that PSS and stress susceptibility existed in 36% of the herds and 44% of the pigs (Livestock Conservation Institute, 1971). The incidence of PSE can run as high as 80% in some herds.

Pork producers in the U.S. have recognized the problem and have changed their breeding programs to cull out stress susceptible breeding stock. As a result of this program, the incidence of stress susceptible animals nationally (measured by lowered meat quality) has been reduced from 44% in 1971 to 20% in 1978 (J. Marchello, personal communication). In Arizona, the incidence of stress susceptibility has been reduced from 30% in 1974 to 5% in 1978 (Arizona Pork Producers Association, personal communication). Arizona producers have a strong economic incentive to improve their breeding programs since the hot summer weather in Arizona would increase death losses from genetic stress susceptibility. In addition, most of the pigs raised in Arizona come from large farms which follow a good breeding program. in the Midwest by contrast, a high percentage of farms are small operations which lack the necessary expertise and resources.

Pigs with inherited stress susceptibility have a much lower tolerance to handling stress, changes in temperature, physical exertion and excitement, and are more likely to die (PSS) or have lowered meat quality (PSE) than normal pigs. Not all pigs with the stress susceptible syndrome have lowered meat quality or die but mixing strange animals together, with resultant fighting to determine social order, is a common cause of death in these animals. Stress susceptible pigs will react to handling stress or physical exertion by sudden panting and, possibly, the appearance of a splotchy, red, checkerboard pattern on the skin (E. Bicknell, personal communication). This pattern is created by the dilation and contraction of small blood capillaries in different areas (Ball *et al.,* 1973). These pigs usually have a higher body temperature than normal pigs when exposed to handling stressors, experience an increase in breathing rate, and may appear weak and reluctant to move (Topel *et al.,* 1968). In fact, pigs with severe cases of stress susceptibility have symptoms similar to those seen in human beings with the genetic defect called malignant hyperthermia (See *Int J Stud Anim Prob 1(3):*153-154, 1980).. In such individuals, certain stimuli can trigger sudden, rapid rises in temperature—113°F in man or 118°F in pigs (Williams *et al.,* 1978). Another sign of stress susceptibility is a nervous animal with trembling ears and constant tail switching (Livestock Conservation Institute, 1971). If such animals become excited or exert themselves, they may collapse. The final stage prior to death is muscular rigidity and extreme hyperthermia. Death occurs in 80% or

more of the pigs reaching this stage although an injection of propranolol—an epinephrine antagonist—frequently produces complete recovery (Topel, 1979).

In stress susceptible animals, there are strong indications that the endocrine system is abnormal and there may be abnormalities in intermediary metabolism as well. For example, pigs in the final stages of muscular rigidity during the stress syndrome have extremely high levels of lactic acid and Topel (1979) suggests that stress susceptible pigs may have a defect in lactic acid metabolism—specifically, in its synthesis into glycogen in the liver.

Van der Wal (1970) reported that stress susceptible pigs had a greater rise in plasma epinephrine after being prodded with electric prods than normal pigs, and others have noted that susceptible animals have higher ACTH levels without a corresponding rise in glucocorticoid levels (Marple and Cassens, 1973). (ACTH from the pituitary stimulates the secretion of glucocorticoids from the adrenal.) Pigs which die from PSS had been shown to have large lipid masses in their adrenal glands (Ball *et al.*, 1973), and it was suggested that such lesions would result in hypofunctionality—that is, less glucocorticoid would be secreted. Later research indicated that stress susceptible pigs may have an overactive anterior pituitary (Kraeling and Rampacek, 1977; Kraeling *et al.*, 1975) and that stress susceptible pigs metabolize glucorticoids three times as fast as normal pigs (Marple and Cassens, 1973). Topel (1979) reports that stress susceptible pigs require more cortisol than normal pigs in order to stimulate lactic acid metabolism and he comments that "an abnormality of the adrenal gland does not appear to be part of the etiology of the stress syndrome." The actions and interactions of B-endorphin, growth hormone and thyroid hormone also need to be studied. (Stress affects thyroid hormone levels—Moss and Robb, 1978.) Williams *et al.* (1978) reports stress susceptible pigs have higher levels of histamine, dopamine, norepinephrine and serotonin.

The meat from stress susceptible pigs is usually of much lower quality, especially if the animals become excited prior to slaughter. PSE meat is paler, softer than normal and has a lower pH. In Australia, where the criterion for PSE meat is a pH of 5.8 or below. The incidence of PSE meat has been reported to be 2-10% (Baumgartner, 1979). In Alberta, Canada, the incidence of PSE meat was reported at 21% but a cut-off point of pH 6.0 was applied (Westra *et al*, 1979). This difference, and the fact that pH values of meat are affected by the stunning method used and the time elapsed between slaughter and measurement, illustrates the need for standardized techniques.

PSE meat has a poor ability to retain water (carcasses in the cooler are characterized by puddles of water under them), is less juicy (Hedrick, 1965), shrinks more during cooking, and has a shorter shelf life due to its tendency to turn an ugly gray color (Topel *et al.*, 1976). Both consumers and a trained taste panel preferred normal pork chops to PSE pork chops (Topel *et al.*, 1976). Another undesirable condition in meat from PSE pigs is two-toned ham.

It is difficult to calculate the losses to the pork industry from PSE meat because pork is made into so many different types of products before it leaves the processing plant. Kaufman *et al.* (1978) estimated that pork shrinkage during transit of PSE pork could exceed 2.25 million pounds annually in the United States. This is a very conservative estimate and would produce wholesale losses of about $4.5 million. An interview with a major midwestern meat packer indicated that

less than 1% of the PSE hams or loins had to be ground up into sausage meat due to lack of quality, but greater shrinkage during smoking in smoked hams and the shorter shelf life of PSE meat results in substantial losses. Uncured PSE hams shrink 1.51% during transit compared to 0.45% for normal hams and, during smoking and chilling, PSE hams shrink 5.71% compared to 3.95% in normal hams and 1.64% in dark, firm hams.On the average, Kaufman *et al.*(1978) concluded that PSE meat shrinks 3% more than normal. For one large midwestern pork slaughter plant, which slaughters 4000 pigs daily and has an average incidence of 15% PSE hams, the annual losses could run to $150,000.

Prevention: The main method of preventing stress susceptibility, PSS and PSE is through selective breeding. Stress susceptibility became a problem when producers selected for high meat producing pigs since stress susceptible animals were usually more efficient converters of feed, consumed less feed and tended to have larger loin eyes (bigger chops) than normal pigs (Carlson *et al.*, 1978). Fortunately, not all high producing pigs carry the stress susceptibility trait. Pigs which are genetically stress susceptible have larger diameter muscle fibers, but if muscling can be increased by increasing the number of fibers instead of their size, then stress susceptibility should no longer be a problem (Topel, 1979). Pigs with PSE meat also have more large white muscle fibers and a poorly developed network of blood capillaries (Merkel, 1971).

A simple test called the "CPK Screen" has recently become available to pork producers from Genetic Information Systems in Elk Grove, Illinois. The test costs approximately $2.00 per animal and consists of taking a drop of blood from an animal's ear (after it has been run for 100 yards) and placing it on a special card which is then sent to Genetic Information Systems for readings (Addis, 1976). The test measures the blood levels of an enzyme called creatine phospho-kinase since pigs with inherited stress susceptibility tend to leak greater amounts of this enzyme from their muscles into the blood than normal pigs when physically exerted or excited. (Lab procedures and further details may be found in Hwang *et al.*, 1977). Double-muscled cattle which tend to be dark cutter prone and more excitable also have higher CPK levels than normal animals (Holmes *et al.*, 1973) and a modified CPK Screen may be useful in this instance as well.

The CPK test is mainly a screening device and the producer with a serious problem with inherited stress traits should use the Halothane test for a more definitive answer. Stress susceptible pigs react to Halothane anesthesia by becoming rigid while normal animals will have no reaction other than falling asleep (Eikelenboom and Minkema, 1974). However, neither of these tests will detect a normal pig which carries the stress susceptibility gene (Topel, 1979) and recent studies by Eikelenboom *et al.* (1978) indicate that the reliability of the Halothane test varies with the breed. The test was accurate for the stress prone Dutch Landrace breed but less accurate for the stress resistant Dutch Yorkshire breed.

Mabry *et al.* (1977) has calculated the probability of the offspring inheriting stress susceptibility and has produced the following figures:

A) Where both parents are positive to the Halothane test, 95% or more of the offspring will be positive.

B) If one parent is positive and the other parent is negative (but has produced

stress susceptible offspring), then 43% of the offspring will be positive.

C) If both parents have produced stress susceptible offspring but are negative in the Halothane test, then 16% of the offspring will be positive.

D) If one parent has produced susceptible offspring but is negative in the Halothane test, and the other parent is negative and does not appear to have the genetic trait, then 0% of the offspring will be positive.

New tests are being developed for detecting stress susceptibility which will be easier to administer and which will present less risk to the animal. Research on blood typing as method of detecting the stress susceptible trait looks promising (Rasmusen and Christian, 1976; Topel, 1979). The animal does not have to be handled especially for the test since, when the blood is routinely sampled for disease testing, a sample could also be taken for blood typing. Furthermore, the test is capable of detecting carriers of the trait where the genotype is not expressed. Detection of increased levels of white blood cells, lymphocytes and potassium is another possible blood test for stress susceptible pigs (Ellersieck *et al.*, 1979). Early rigor mortis is highly correlated with the incidence of PSE meat (Westra *et al.*, 1979). Davis *et al.* (1978) have used the angle of the foreleg to determine the amount of rigor before carcasses go into the cooler. If pigs are stressed prior to slaughter, the accuracy of rigor and pH tests done shortly after slaughter will be affected (Barton-Gade, 1980).

Stunning Techniques and Meat Quality

Any stunning method produces a mass stimulation of the animal's nervous system. There have been many studies on the stressfulness of various methods of stunning but, in most cases, no differentiation was made between the stress which occurs before the onset of unconsciousness which would cause the animal discomfort or pain and stress which occurs after unconsciousness. However, the physiological mechanisms of stress are the same before and after unconsciousness.

All stunning methods trigger a massive secretion of epinephrine and other catecholamines in cattle, sheep and pigs (Pearson *et al.*, 1977; Van der Wal, 1978; Warrington, 1974). In sheep the levels of epinephrine induced by electrical stunning were higher than the levels which could be induced by environmental or psychological stressors (Pearson *et al.*, 1977). All stunning methods increased catecholamine levels by a factor of seven in pigs (Ratcliff, 1971). However, modern stunning methods usually do not affect glucocorticoid levels because of the slower rate of glucocorticoid secretion. Pearson and colleagues (1973) reported that it takes three minutes for glucocorticoid secretion to rise after the onset of the stressor.

Epinephrine and other catecholamines which are released during stunning increase the incidence of PSE meat in pigs. However, the color of beef may actually be improved by the epinephrine triggered during captive bolt stunning and this would be especially true of animals which had endured prolonged stress prior to stunning. The beef animal or lamb should be bled as soon as possible after captive bolt stunning since, if epinephrine is allowed to circulate for more than a few minutes, it may toughen the meat. It has been reported that meat from

calves slaughtered without stunning by Kosher method was slightly more tender than animals killed with a captive bolt (Westervelt *et al.*, 1976). However, this was only true when the calf was held in a restrainer in an upright position while its throat was cut—stress from shackling and hoisting a conscious animal tended to toughen the meat. Acute stress, which causes epinephrine to be secreted at high levels for 10-30 min prior to stunning, is also detrimental to meat tenderness. In a well-managed and designed beef slaughter plant, five minutes is the maximum interval between stunning and bleeding.

Pigs

In pigs, it is desirable to use a stunning method which produces painless unconsciousness with a minimum of epinephrine secretion. Althen *et al.* (1977) compared rifle, electric stunning (3.5 amps, 240 volts, 10 sec) and no stunning. Blood epinephrine increased to 108 ng/ml after gunshot, to 18.8 ng/ml after electric stunning and was 1.6 ng/ml in the unstunned animals. The blood samples were taken immediately after stunning, before the throat was cut. From this study, it was concluded that neither gun shot nor captive bolt is recommended for 180-250 lb market weight pigs. This is in agreement with the findings reviewed by Marple (1977). Scheper (1977) reported that captive bolt and CO_2 stunning accelerated the breakdown of muscle glycogen more than electric stunning.

The incidence of PSE carcasses can be reduced by using a shorter application time for electric stunning (Marple, 1977; Van der Wal 1978). When electric stunning is used, epinephrine secretion stops when the current stops flowing. With captive bolt or gunshot methods, the epinephrine continues to be secreted until the animal is bled (Van der Wal, 1971). Both Marple (1977) and Van der Wal (1978) recommend using 300 volts with an application time of just a few seconds for stunning to reduce the incidence of PSE meat. A typical short application time is 1-5 sec. Lower voltage electro-coma stunning is applied for 14 sec or longer (Carding, 1971) and increase the incidence of PSE meat (Scheper, 1977). The stunning recommendations made by Hoenderken (1978*a,b*) are the best from the standpoint of both meat quality and painlessness.

Another reason why captive bolt or gunshot is detrimental to meat quality in market weight pigs is that it causes intense struggling (McLoughlin, 1971) which results in lower muscle pH (Van der Wal, 1978) and possibly blood splash (See below). When electric stunning is used, pigs should be bled while they are still in the tonic, rigid phase of the grand mal seizure since this will reduce detrimental muscular activity (Warrington, 1974).

Carbon dioxide anesthesia causes a higher incidence of PSE pork carcasses than either captive bolt or electric stunning (Van der Wal, 1978). Carbon dioxide has a direct effect on blood pH in both pigs and sheep (Mullenax and Dougherty, 1963, 1964) and the struggling which takes place while the animal is losing consciousness further contributes to the lowering of the muscle pH due to lactic acid formation caused by the breakdown of muscle glycogen (McLoughlin, 1971). Scheper (1977) and Overstreet *et al.*, (1975) also reported that CO_2 anesthesia lowered the pH in muscles more than electric stunning.

The Butina Company has developed a CO_2 unit (see Grandin, 1980) called the Compact Plant which reduces struggling. Because of the restraint, this type of CO_2 unit is preferred by Hoenderken (1978*a*). Carbon dixoide units also eliminate

internal bleeding and CO_2 enhances bleed out (Warriss, 1977). When CO_2 units were first introduced in the 1950's, PSE was seldom a problem because lard-type pigs, which had high muscular pH and tended to have dark, firm, dry meat as a result, were used. Carbon dioxide anesthesia actually improved meat quality, and this is still the case in Ireland (Gallwey and Tarrant, 1978).

Blood Splash

Blood splash is a condition which can occur in all types of livestock and which "seems to be caused by a combination of increased blood pressure and severe muscle spasm induced by stunning" (Leet *et al.*, 1977). The incidence of blood splash is often related to the stunning method used, but in all animals, blood splash can be reduced by reducing the interval between the onset of stunning and bleeding. Blood splashes are small hemorrhages which may occur throughout the meat and internal organs and, in pigs, can range in size from pin heads to splotches half-an-inch in diameter. Similar blood splashes can occur in sheep, cattle and calves although blood splashes are seldom a problem in cows and steers. A problem often seen in pigs is bleeding in the shoulder or ham (Leach, 1978). This is caused by rupturing of a blood vessel during struggling in the shackling process. Pigs stunned with CO_2 have a lower incidence of blood splash than electrically stunned pigs (Larsen, 1978).

Blood splash is most likely to be caused by a combination of increased blood pressure and muscular activity after stunning. For example, electrical stunning increases the blood pressure in sheep by a factor of 3.5 (Kirton *et al.*, 1978). Blood pressure may be a factor in blood splash but is certainly not the sole cause. Van der Wal (1978) and Leet *et al.*, (1977) state that strong muscle spasms after stunning increases the incidence of blood splash. Any method which reduces reflexive struggling after stunning will probably reduce blood splash and Kirton *et al.* (1978) found that there was less blood splash in sheep slaughtered without stunning compared to those slaughtered with electric stunning.

Marple (1977) has reported that blood splash could be reduced in pigs using a high frequency 1,300 Hz current in electrical stunning. One of the reasons why high frequency electrical stunning may reduce blood splash is that it can sometimes fail to produce unconsciousness in the pig. As a result, the grand mal seizure and its associated muscular contractions may not occur. High frequency stunning is not recommended until it can be demonstrated that it reliably induces unconsciousness. In sheep, it has been reported that blood splash is a problem in some groups and not in others (Pearson *et al.*, 1977) and that there is less blood splash in animals stunned by concussion rather than electricity (Blackmore, 1975; Spencer, 1979).

As has been noted, the incidence of blood splash can be lowered by reducing the interval between stunning and bleed-out although blood splash can still occur even after the jugular vein has been cut (Leet *et al.*, 1977; Warrington, 1974) or if the animals are bled while the current from the electric stunner was still passing through them (Ratcliff, 1971). However, bleeding sheep immediately after removal of the electric stunner resulted in a lower incidence of blood splash than bleeding 5-8 sec later (Blackmore and Newhook, 1976; Kirton *et al.*, 1978). It has also been reported that a lower incidence of blood splashed hams are seen in electrically stunned pigs when the stunning to bleeding interval was reduced to

15 sec (Calkins *et al.*, 1980). Furthermore, to reduce the effect of the severe muscular contractions which occur during stage 2 (clonic phase) of the grand mal seizure, electrically stunned animals should be bled while they are still in the rigid (tonic) phase of the seizure.

Bleed Out

Animals lose about 60% of their blood during bleed out, 15-20% remains in the meat and 25-20% in the internal organs. The amount of blood remaining in the internal organs and meat varies but these small differences will not affect the keeping qualities (Warriss, 1977). Any stunning method may enhance bleed out due to constriction of peripheral blood vessels triggered by epinephrine secreted after stunning (Warriss, 1978). Carbon dioxide anesthesia produced the best bleed out, with electrical stunning second, captive bolt third and no stunning last. For example, electrically stunned sheep lost 9% more blood than captive bolt stunned animals (Warriss and Leach, 1978) and the *National Provisioner* (1956) reported that a greater volume of blood was collected when they converted from bleeding conscious, shackled pigs to CO_2 anesthesia. Warriss (1977) also cited a study which reported that electrically stunned pigs had less blood in their muscles than unstunned animals. In cattle, captive bolt stunning is essential for maximum blood collection. Tests in a plant visited by the author indicated that, if an animal had to be shot twice with the penetrating captive bolt, 10% less blood was collected, and shooting in the poll could result in a reduction of 50% in the amount of blood collected.

A general recommendation is that bleed out will be facilitated if the interval between stunning and bleeding is as short as possible. There is also evidence that pigs may bleed out more rapidly when in the prone position (Blackmore and Newhook, 1976; Von Mickwitz and Leach, 1977) and that electrically stunned sheep bled horizontally yielded 10% more blood than animals hung vertically (Leach and Warrington, 1976). If CO_2 is used, care must be taken not to get the gas concetration too high or the animals will not bleed out as well (Ratcliff, 1971). The use of electrical tenderizers may improve bleed out (Kane, 1979).

Conclusion

Obviously, the ideal solution from the point of view of stressors and livestock handling and meat quality is to have unstressed animals. However, the review by Hedrick (1965) indicated that certain types of prolonged stress 24 hours prior to slaughter may improve or not change some aspects of meat quality but other aspects could decline. Any possible economic benefits of stressing animals on purpose would be offset by bruising accidents to handlers and death losses. For example, slightly dark cutting beef is often more tender but it has decreased flavor.

Acute stress shortly before stunning almost always has a detrimental effect on meat quality according to most of the studies reviewed. However, there were some conflicting results between the various studies reviewed. There appears to be distinct differences between the effects of excitement and stress immediately prior to stunning and the effects of stress 12-48 hours before stunning. These differences cannot be completely explained by pH changes, glycogen metabolism

or lactic acid metabolism and more research is needed to understand the interacting physiological biochemical factors.

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