DISSERTATION

CARCASS BRUISING LOCATION AND BRUISE TRIM LOSS IN FINISHED STEERS, COWS, AND BULLS AT FIVE COMMERCIAL SLAUGHTER FACILITIES

Submitted by

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ABSTRACT

CARCASS BRUISING LOCATION AND BRUISE TRIM LOSS IN FINISHED STEERS, COWS, AND BULLS AT FIVE COMMERCIAL SLAUGHTER FACILITIES

Determining the location of, and investigating possible causes of, bruising in beef carcasses is critical for addressing animal well-being concerns in the livestock industry—as well as understanding losses in value that are a consequence of carcass defects. This study was conducted in five commercial slaughter facilities, located in multiple regions of the U.S., that slaughter fed steers/heifers, cows and bulls. At each plant, animals from thirty trailers, at least one animal from each utilized compartment. In total, approximately 50 animals were marked each night, providing 150 marked animals over the three days of sampling at each facility. Individual carcasses were followed through the slaughtering process and were evaluated before carcass splitting for: presence/absence and location of bruising, and the weight of bruised meat that was removed from carcasses during trimming. This study found that 28.1% of carcasses observed were visibly bruised. Regions of the carcass that had the highest bruise incidence were the round, rib, and loin beef cuts, respectively. However, some carcasses had deep tissue bruises that were not visible on the surface of the carcass, but trim loss was collected once these bruises were exposed and averaged 1.0 kg per carcass. Cattle in the top deck compartment were less likely to be bruised when compared to cattle in the belly compartment ($P = 0.03$). Reduction of bruising enhances animal well-being and reduction in trim loss adds economic efficiency along the entire beef supply chain.

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Chapter I

INTRODUCTION

There are several factors that affect cattle well-being during commercial transport to slaughter facilities. These factors can include human stressors such as the driving experience of the truck driver. Transportation factors could also include too low or high ambient temperature, trailer type, trailer noise and vibration, origin of loading, road condition, and the total journey time, too low or high space allocation, and vehicle design. Animal handling and deprivation of water and feed can also be stressors the cattle may be exposed to in commercial hauls to slaughter facilities (Dodt et al., 1979; Broom, 2003; Fazio and Ferlazzo, 2003; Minka and Ayo, 2009; Huertas et al., 2010; González et al., 2012; Gonzalez et al., 2012b; Mendonça et al., 2018) which all can impact animal well-being.

Broom (2000) stated that bruises, carcass quality, mortality, and injuries can all be used as livestock well-being indicators to assess handling and transport. Mortality records can provide information on livestock well-being during the journey, but bruises, injuries, blemishes, and carcass defects can provide information about the livestock well-being during transport, handling, and lairage (Broom, 2000). Bruises can cause economic loss in the beef industry and are indicators of potential animal well-being concerns during pre-slaughter animal handling management (Jarvis et al., 1995). The estimated economic loss from bruising widely varies across studies/countries (Meischke et al., 1974; Shaw et al., 1976; Grandin, 1980; National Cattlemen's Beef Association, 2017).

This study expanded on the Lee et al. (2017b) study by evaluating bruising on an individual animal basis. The present study provides new insights into bruising incidence rates, trailer compartment differences, bruise trimming incidence, cattle trailer operator experience, cattle body condition score, and cattle sex class differences within the fed and cull cattle industry. This current study includes individual animal evaluation from cattle unloading to carcass bruise trim removal, allowing in depth assessment of bruises and their impact on animal well-being and the economic impacts on the cattle industry. This study was aimed to assess trailer unloading and trailer compartment as a critical control point for bruising in the livestock supply chain.

Chapter II

LITERATURE REVIEW

Definition Of A Bruise

Bruising of cattle is most commonly caused by blunt and/or squeezing force trauma (Marshall, 1977; Nash and Sheridan, 2009; Venes, 2009). A majority of the scientific bruise or contusion research has been conducted in the human medical field for domestic and child abuse victim court testimony, and the difference in human and animal physiology has been acknowledged (Langlois and Gresham, 1991; Nash and Sheridan, 2009). Many animal bruise studies were conducted before strict oversight from institutional animal care and use committees (IACUC) and this research is still referenced today. A bruise is foremost the site of an injury/contusion and can be defined as an 'extravasation of blood beneath an intact epidermis due to injury' (Capper, 2001). A bruise can also be defined as a special type of hematoma that has a focal point of discoloration caused by a blood collection that can be seen with the naked eye, that occurred due to trauma to the body ante-mortem (Marshall, 1977; Capper, 2001; Langlois, 2007; Pilling et al., 2010). Three core criteria must be met for a bruise to occur: (1) the skin and tissues must be stretched and/or crushed with enough force to cause the small blood vessels to rupture, but not break the surface of the skin (the trauma must be caused by a blunt force so that the skin is not punctured as to cause a laceration), (2) there must be sufficient blood pressure within the blood vessels to move the blood from the damaged vessels to the surrounding areas, (3) the blood that leaves the blood vessels must be close to the surface of the skin to be visible with the naked eye for surface bruises (Langlois, 2007; Pilling et al., 2010). However, the term 'bruise' is not synonymous with petechiae, ecchymosis, and/or purpura because these hemorrhages of the skin are best categorized as leakages of blood under the skin or rashes which are not caused by blunt or squeezing force trauma (Stedman, 1972; Sheridan and Nash, 2007). The collection of escaped blood for deep tissue bruises will not be readily visible on the surface due to the location of the trapped blood in the body tissues. The severity of a bruise is dependent on the amount and size of the blood vessels that are ruptured at the time of trauma which can vary from a bruise of little significance to a significant contusion/bruise (Marshall, 1977).

Bruise Physiological Response

Blood contains hemoglobin which is responsible for transporting oxygen from the lungs to the other tissues of the body (Langlois, 2007). The red discoloration in a contusion or bruise is the result of the hemoglobin that is present in the red blood cells that is released from the damaged tissues due to the injury (Nash and Sheridan, 2009). The release of hemoglobin and/or red bloods cells initiates an inflammatory response within the body which includes vasodilation, and this attracts macrophages to the traumatized area (Nash and Sheridan, 2009). Redness of the skin and freshly escaped blood is then replaced by a blue or purple color due to the deoxygenated venous blood into the various body tissues (Pimstone et al., 1971; Nash and Sheridan, 2009). Macrophages then ingest the free erythrocytes and degrade the attached hemoglobin on the red blood cells (Nash and Sheridan, 2009). Hemoglobin begins to breakdown, by first converting to biliverdin, which contributes to the green color seen in a healing contusion (Hughes et al., 2004b). Biliverdin then is converted to bilirubin which accounts for the yellow color seen in a healing bruise injury (Vanezis, 2001b). Throughout this process, some of the escaped iron can combine with ferritin which creates hemosiderin, which can have a brown appearance in tissues (Hughes et al., 2004a).

Bruise Color And Aging Cycle

Perception of color, such as green, blue, yellow, purple, black, orange, brown or red, does not indicate anything about the age of a bruise; different species of animals can have varying bruise color progressions and presentations (Hamdy et al., 1957c; McCausland and Dougherty, 1978; Langlois and Gresham, 1991; Langlois, 2007). Statements that ‘a blue bruise is recent’ or ‘a fresh bruise will be red’ cannot be substantiated because different tissues have various color retain properties and there is inherent individual variation (Langlois, 2007). The perception of the color of a bruise will change as the position of the trapped blood under the skin surface and the process of hemoglobin converting to oxyhemoglobin which then converts to deoxyhemoglobin changes (Langlois, 2007). Some authors have published guidelines for bruise color appearance (Hamdy et al., 1957c; Langlois and Gresham, 1991), while others claim it is not possible to age a bruise solely based on color (Langlois and Gresham, 1991). However, a general consensus seems to exist on the progression of the color changes of a bruise, but the exact time periods that match these color changes are debated (Langlois and Gresham, 1991). The generally accepted color cycle of a bruise is that red, purple and blue are the early appearing colors, green appears after red, blue, and purple (between days 4-7) and yellow appears after green (not until at least day 7) (Langlois and Gresham, 1991). Hamdy et al. (1957c) conducted a study in cattle that found the red bruise color could persist from 15 minutes to 2 days from the red blood cells and free hemoglobin in bovine tissue, green could be seen on day 3 to 4, and yellow and orange could be present days 4-6 from the bilirubin in the tissues. Hughes et al. (2004b) stated that as an individual’s age increases, the eye’s ability to detect the color yellow decreases and this could have an effect on observations of bruise color with the naked eye. Individuals in their late teens tend to perform the best with color hue testing, and gender does not have an effect (Hughes et al., 2004b).

More studies were performed in cattle and rabbits and it was discovered that order of the color changes remained consistent between species, but that the age of animals affected the rate at which the color changes occurred (Hamdy et al., 1957b; Hamdy et al., 1961b). McCausland and Dougherty (1978) conducted a study in calves and reported that the color 'yellow' appeared in bruises within 48 h, which contradicted earlier studies claiming that yellow color does not appear until day 7 at the earliest. There is much disagreement in the scientific community about only using color to age the appearance of a bruise (Langlois and Gresham, 1991).

Factors Affecting Bruising

Factors that can affect appearance of a bruise can include environmental temperature, laxity of tissues, whether the tissue is near a bone surface, age of the individual when the bruise occurs, pre-existing diseases, force and velocity level at impact, and pre-existing bruise trauma to the location (Hamdy et al., 1961a; Hamdy et al., 1961b; Langlois and Gresham, 1991; Randeberg et al., 2007). The location of the injury can affect the amount of hemoglobin released from the vessels due to a bruise, such as, if the area is low in connective tissue and high in adipose tissue and vascularity, there can be a larger amount of blood released (Johnson, 1990; Vanezis, 2001b). Environmental temperature affects bruise healing rate of chicken broilers because birds kept in colder temperatures healed at a slower rate and the bruises had overall more yellow color present in the tissues (Hamdy et al., 1961a). Vanezis (2001a) stated that age of the individual can also have an effect on the bruising process, especially if the individual is elderly and has thinning skin and the tissue around the blood vessels is weakened. Hamdy et al. (1957b) found, in a study conducted on rabbits, that bruises in younger rabbits (2-5 months old), compared to bruises to older rabbits (5-8 months old), healed much more quickly in the younger animals than in the older animals. These findings support work performed in the 1930s by Howes and Harvey (1932), which stated wounds heal faster in the young than they do in the elderly population. Hamdy et al. (1957b) also used cattle and rabbits to assess the rate of healing of multiple bruises (3 bruises total), and found that when a rabbit is bruised multiple times, the third bruise inflicted healed an average two days faster than the first and second bruises.

The mass and velocity of the object causing the bruise can affect the extent and severity of the bruise; however, the sequence of visible and chemical changes of the bruise healing process remain constant (Hamdy et al., 1957b). Barington and Jensen (2016) stated that, when examining a bruise, the amount of force used and the time lapse since the incident need to be considered, not only the amount of time since the trauma occurred. Using twelve porcine models, a study was conducted to evaluate histological and gross changes in tissues at 2, 4, 6, and 8 hour following bruise infliction, which were caused by low, moderate, and high force levels. All pigs were anesthetized during this study and appearance of bruises was similar for all force levels until the 0.5 hour mark. At this time point, visibility of the bruise depended on the amount of force used to inflict the bruise (Barington and Jensen, 2016).

A study was conducted in cattle that applied force before and after exsanguination, and it was determined that a bruise could form before and after stunning, but not after exsanguination when the blood pressure of the animal was close to zero (Hamdy et al., 1957b). Meischke and Horder (1976) stated that bruising is possible after an animal falls out of the ‘knock box’ after stunning, but if the ‘stun to stick’ interval is decreased, then this can decrease the amount of bruising. The depth of the injury also can affect the time it takes for a bruise to appear on the surface of the dermis; superficial bruises can appear almost immediately after the trauma occurs, while deep tissue bruise can take hours to appear or not appear at all on the surface due to the body initiating a inflammatory response (Langlois and Gresham, 1991). Studies conducted on bruising cattle, with a 7 pound sledge hammer, found that the most swelling due to fluid volume occurred within two days of the inflicted contusion, the most biochemical changes within the bruised tissues occurred on the fourth or fifth day after the bruise was inflicted, and the biochemical levels in the body returned to normal on the ninth day (Hamdy et al., 1957c).

Bruise Detection And Aging Methods

Langlois (2007) stated that the eye's ability to perceive the initial site of trauma is caused by the appearance of the blood that has been released underneath the skin, and that this can occur as quickly as 15-20 minutes after the time of injury. Visual assessment has long been the most practical and easiest method for bruise identification and aging of bruises (Trujillo et al., 1996). This by nature is a subjective measurement and more objective measurements to determine a bruise's age are desired (Hughes et al., 2004a). Hamdy et al. (1957a) stated that, on slaughtered animals, the method most used is 'gross observation and color changes' to assess bruises. Strappini et al. (2012a) conducted a study in Chile to visually score bruising in commercial cattle abattoirs to assess the size, color, severity, shape, and bruise distribution over beef carcasses from video recorded in the abattoir. It was observed that there was a high level of intra-observer reliability and a low level of inter-observer reliability among bruise evaluators of postmortem carcass bruises (Strappini et al., 2012b). More objective methods that have been considered for bruise assessment include colorimetry, reflectance spectrophotometry, concentration measurements of hemoglobin and bilirubin in vivo, and histology (Hughes et al., 2004a; Langlois, 2007).

Colorimetry uses white light and three receptors that detect blue, red, and green regions on the color spectrum (Langlois, 2007). The output of the color detection, of the colorimeter, can measure color differences that can be quantified as L*a*b* where L* represents the luminosity or brightness of the color, a* represents the green – red spectrum, and b* represents the blue – yellow spectrum (Langlois, 2007). A limitation of colorimetry is that the background color of the skin confounds the ability of the colorimeter to accurately age bruises with only three data points to reference (Langlois, 2007).

Spectrophotometry measures the color intensity in 1 nm intervals of color wave lengths of red to blue (Langlois, 2007). By measuring the proportion of oxygenated hemoglobin that appears in the bruise and the amount of deoxyhemoglobin data could be collected in the first stages of aging a bruise (Randeberga et al., 2004). Infrared spectrophotometry penetrates deeper into the skin and could offer information on the water and hemoglobin content of the tissues (Attas et al., 2001; Langlois, 2007). Ultraviolet light, such as the "polilight®" used by several police forces, has been used to study bruise aging, but this method has not proven to be useful in aging bruises (Hughes et al., 2006; Langlois, 2007). Chemical aging or hyperspectral imaging, combined with digital imaging that has been used by law enforcement for finger print analysis, could possibly be applied to aging bruises (Exline et al., 2003). Hyperspectral imaging uses a spectrophotometer, which measures light reflection in wavelengths, the lens captures a full spectrum image of the bruise or fingerprint and the chemical imaging separates the image based on the color wavelengths present in the high quality image (Exline et al., 2003; Langlois, 2007).

Measuring concentrations of hemoglobin and bilirubin in tissues was found to be consistent across muscle location and various animal species (Hamdy et al., 1957a). The pigment from bile liquid, bilirubin, forms during the healing process of a bruise from the degradation of the hemoglobin molecules, and this color test was based on the presence or absence of bilirubin in bruised tissues (Hamdy et al., 1957a). The amount of bilirubin peaks at day 4 and slowly decreases until it's completely absent once the bruise has healed (Hamdy et al., 1957a). Healing was assessed by the presence of bilirubin which was detected using the Fouché's reagent in bruised tissues after the animals were euthanized in the study (Hamdy et al., 1957a; Hamdy et al., 1961a). Tissues were tested immediately after exsanguination, using Fouché's reagent; tissue was immersed for 10-20 minutes at room temperature then the color of the tissue was evaluated. Color results were able to be replicated in cattle, lambs, and rabbits (Hamdy et al., 1957a). Normal tissues showed no color change in the Fouché's reagent, fresh bruises (0-60 h) turned pink and then faded to brown, intermediate bruises (60-72 h) developed a light blue color at 60 h and blue at 72 h, slightly old bruises (3-5 d) developed a dark green and brown color, and old bruises (5-8 d) developed slight blue color and green crystals were found to be in the bruised tissue (Hamdy et al., 1957a). The color test also was performed on the hides of cattle that were bruised and it was found to be only effective on the areas the bruises were inflicted, which suggested that biopsy testing may be possible to assess the age of a bruise on live animals (Hamdy et al., 1957a). The detection of the colors were more easily observed in the adipose tissue compared to lean tissue, and 50-100 ppm of bilirubin albumin were needed to elicit a light blue color change in the bruised tissues (Hamdy et al., 1957a).

Histological evaluation of aging bruises has not been studied extensively in the literature, but a study by Thornton and Jolly (1986) was conducted in sheep using histology as the method of assessing bruise age. The authors used the Bayesian probability model to quantify bruise histological data. This study utilized fifty Romney or Perendale lambs that had up to six impact bruises inflicted on each animal using a 1500 g lead weight through a tube 1.0 m in length (Thornton and Jolly, 1986). At predetermined time points, lambs were euthanized and bled out. Then, three tissue samples 7.0 mm thick were obtained from animal that included fat and muscle (Thornton and Jolly, 1986). Tissues were preserved and fixed in a 10% formol saline and the tissues were scored on a scale of 1 to 4 to assess inflammation, repair, and degeneration. Muscle and adipose tissue ratings included "1" as normal tissue and "4" as severely damaged tissue (Thornton and Jolly, 1986). Hemosiderin also was evaluated for presence or absence, which is the yellowish pigment that can be found in macrophages (Thornton and Jolly, 1986). Bailey (1965) stated that the Bayesian probability model uses Bayes' theorem about inverse probabilities. Stam et al. (2010) found that by 3D computer modeling of hemoglobin and bilirubin formation of a bruise could assess how skin thickness and bruise diameter differed for symmetric circular bruises and natural inflicted bruises. Barington and Jensen (2016) conducted a study finding that the number of subcutaneous macrophages and neutrophils in muscle tissue of pigs from bruises inflicted at 2, 4. 6, and 8 hours was a useful method of aging bruises.

Transport Bruising Factors And Stress

Transport stress is one of the most common types of stressors in the livestock industry and majority of cattle will be transported at least once in their lifetime (Warriss, 1990; Swanson and Morrow-Tesch, 2001; Broom, 2003; Warriss, 2004; Broom, 2005; Adenkola and Ayo, 2010; Thomson et al., 2017). McNally and Warriss (1996) stated that cattle origin can play a role in bruising incidence as it was observed that cattle derived from live auctions had more bruises and rejected meat than cattle from farms and dealers, while Meischke et al. (1974) and Shaw et al. (1976) observed that carcasses from horned animals generated twice as much trim as hornless cattle. A study found that majority of cattle bruises occur after the animals have arrived at the slaughterhouse and that efforts to reduce carcass bruising should include slaughterhouse handling procedures and techniques (Meischke et al., 1974; Warriss, 1990).

A 2015 survey of welfare outcomes of cattle on long distance (≥400 km) commercial hauls, in North America found that calves and cull cattle were more likely to arrive non-ambulatory (downer) or dead than were feeder or fat cattle (Gonzalez et al., 2012b). It also was more likely for cattle to become non-ambulatory if the long distance haul was over 30 hours in duration, but the proportion of compromised animals and "shrink" decreased as the driver's experience increased (González et al., 2012; Gonzalez et al., 2012b, a). Gonzalez et al. (2012a) stated that the majority of the drivers had either extensive driving experience (> 10 years) or limited experience (< 2 years) driving cattle trailers on long hauls. There are several factors that cattle are exposed to in commercial hauls, such as experience of the truck driver, too low or high space allocation, handling, too low or high ambient temperature, trailer type, trailer noise and vibration, vehicle design, deprivation of water and feed, type of cattle, origin of loading, road condition, and the total journey time (Dodt et al., 1979; Broom, 2003; Fazio and Ferlazzo, 2003; Minka and Ayo, 2009; Huertas et al., 2010; González et al., 2012; Gonzalez et al., 2012b; Mendonça et al., 2018) which all can impact animal well-being.

When cattle are stocked in trailers at high densities, a loss of balance can cause one animal to involuntarily fall down and remain trapped, in turn causing a domino effect of cattle to fall. Due to this phenomenon, high stocking density was found to be detrimental to animal well-being when compared to medium and low stocking densities in trailers (Tarrant et al., 1988). Randall (1992) stated that there has been little research conducted to determine stability of animals in transport due to the vibrations from the vehicles and trailers. Vibrations can have different effects on human drivers and livestock, including spectrum, frequency, magnitude, direction of action, road condition, orientation of the body, and duration (Randall, 1992; Gebresenbet et al., 2011). Cattle rarely change position while a trailer is in motion, and the cattle typically position themselves at right angles to the direction of travel to try to compensate for the trailer movement and focus energies on keeping their balance (Warriss, 1990). Huertas et al. (2010) conducted a study in

Uruguay to look at transport and carcass bruises and discovered that road conditions can have a bigger impact on carcasses bruising than driver experience.

In an Australian study, 48 Hereford steers were stocked at low (0.89 m^2/animal), medium (1.16 m^2/animal), and high space allowances (1.39 m^2/animal) and transported 360 km to the abattoir. It was observed that ‘low’ space stocking rate caused 6 animals to fall down, while the other treatments resulted in no cattle falling down (Eldridge and Winfield, 1988). It also was observed that ‘low’ space stocking rates caused lower carcass weights compared to ‘medium’ and ‘high’ space stocking rates. However, the ‘medium’ space stocking rate resulted in the lowest bruising rate; the ‘low’ and ‘high’ space stocking rates had 4 and 2 times greater bruise scores (Eldridge and Winfield, 1988). It was suggested that dairy cattle need more than 20 cm above the withers to avoid the cattle from head butting the ceiling of the trailer (Lambooij et al., 2012). There appears to be a correlation between traumatic unloading events and carcass bruising for fed cattle on the dorsal topline body location (Lee et al., 2017a). The correlation between traumatic events at unloading, for finished cattle, and bruising prevalence was low, which indicated that bruising occurs at multiple points in the livestock supply chain (Lee et al., 2016). Lee et al. (2017a) observed that, out of 75 lots of finished cattle, 20.4% experienced traumatic events at unloading; there was a 68.2% average bruising prevalence per lot, and over half of the observed bruises were on the dorsal topline of the cattle. Gonzalez et al. (2012c) stated that most cattle trailers were quad-axle and tri-axles that had five compartments that include the nose, deck, belly, dog house, and back. Sixty percent of the cattle were transported in the deck and belly compartments (middle compartments), thirty percent of cattle were transported in the dog house and rear (the back), and ten percent were transported in the nose (the front)(Gonzalez et al., 2012c). Most cattle appear to be transported in the largest trailer compartments and more driving experience may improve animal well-being outcomes in cattle transport.

Adenkola and Ayo (2010) stated that livestock stressors are usually viewed as an inevitable response to when livestock are exposed to aversive environmental conditions. Stressors can be categorized as psychological stress, which can include handling, novelty or restraint, or also as physical stress which can include fatigue, thermal extremes, hunger, thirst, and injury (Grandin, 1997). Minka and Ayo (2009) stated that stressors in transport also can be classified into as pre-transport stress (poor pre-conditioning), transport stress (distance travelled, duration, climate, speed of travel, road conditions), and post-transport stress (rough unloading, poor unloading ramp conditions, lack of water, food and rest in lairage) to account for each portion of the transportation journey.

Different physiological and behavioral measures of transport stress can include changes in hormones, increased urination, increased defecation, increased respiratory rate, increased rectal temperature, metabolites, restlessness, enzymes, heart rate, and live weight changes (Warriss, 1990; Fazio and Ferlazzo, 2003). Selye (1936) stated that the “general adaptation syndrome” (GAS) for the body to stress can be summarized in three phases; mobilization (alarm reaction), resistance or adaptation, and exhaustion (Selye, 1936). The first phase involves the body’s defense mechanisms, which can include secretions of the adrenal glands, hypochloremia, high blood viscosity, and tissue catabolism. The second phase includes discharge of secretory granules of the adrenal glands and anabolism in the tissue begins to lean towards regaining body weight. In the third phase, symptoms of alarm return and are now overwhelming to the body, which in turn causes exhaustion (Selye, 1936). Broom (2000) stated that bruises, mortality, carcass quality, and injuries can be livestock welfare indicators of handling and transport. Mortality records can provide information on livestock welfare during the journey but bruise, blemishes, injuries, carcass defects give information about the livestock welfare during transport, handling, and lairage (Broom, 2000).

Economic Impact

Bruises in cattle can occur at point in the livestock marketing process including on the farm, during transport, time in lairage, and the time period right after stunning but before exsanguination at the slaughter facility (Warriss, 1990). Marshall (1977) stated that bruised tissues can be considered a public health hazard since bruised tissues can be an ideal environment for pathogenic and spoilage organisms to grow. For these reasons bruised tissues are removed from the carcass before the carcass can be inspected for human consumption (Marshall, 1977). Bruises can cause economic loss in the beef industry and can be indicators of animal welfare concerns during pre-slaughter animal handling management (Jarvis et al., 1995).

In the 1970s, it was estimated that bruising cost the Australian meat industry an estimated $22.5 million per year. In the U.S. meat industry, an estimated $23 million per year is lost to bruising, South Africa estimated that 12% of all carcasses are reject as exports due to bruising, and Northern Ireland estimated that 14% of all carcass condemnations were due to carcass bruises (Meischke et al., 1974; Shaw et al., 1976). It was calculated that US$11.47 was lost per beef carcass in 1994 due to bruising, an annual loss of US$14,452,000 was calculated for the fed beef industry due to bruising in 1998, and in 1999 US$2.24 was lost per carcass due to bruising (National Cattlemen's Beef Association, 1994; Boleman et al., 1998; National Cattlemen's Beef Association, 2017). Bruise trim weights in Australia ranged from 0.68 kg to 7.35 kg per carcass (Meischke et al., 1974). Dodt et al. (1979) discovered, in Australia, that despite a popular perception that fasting cattle before transport decreases bruises, the longer the cattle were fasted

(0 hours, 24 hours, 48 hours), the more bruise trim was removed from carcasses. It was also observed that horned cattle had twice as much bruise trim as hornless or polled cattle (McManus and Grieve, 1964; Meischke et al., 1974; Shaw et al., 1976; Grandin, 1980). Since the first National Beef Quality Audit in 1991, horn prevalence has decreased from 31.1% to 16.7% in U.S. finished cattle (Eastwood et al., 2017). In NBQA-2016, it was observed that 90.3% U.S. beef cows were hornless, 82.7% U.S. beef bulls were hornless, 87.9% U.S. dairy cows were hornless, and 69.0% U.S. dairy bulls were hornless (Harris et al., 2017).

McNally and Warriss (1996) observed 16,000 animals and noticed that derived cattle from auction markets had more bruising than cattle from direct buyers, and conditions that caused bruising seemed to be stressful cattle as well. Any bruised tissue trimmed from a beef carcass reduces the carcass value and yield (Warriss, 1990; McNally and Warriss, 1996). The National Beef Quality Audit 2016 (NBQA-2016) for fed cattle documented that 38.8% of observed U.S. finished cattle carcasses were bruised, 64.1% of observed U.S. cow carcasses were bruised, and 42.9% of observed U.S. bull carcasses were bruised (Eastwood et al., 2017; Harris et al., 2017). Lewis et al. (1962) observed that pre-slaughter stress had a negative effect on beef palatability characteristics which can have an economic impact on consumers’ choice to purchase beef products.

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Chapter III

FIELD OBSERVATION: PEN STOCKING CAPACITIES FOR OVERNIGHT LAIRAGE OF FINISHED STEERS AND HEIFERS AT A COMMERCIAL SLAUGHTER FACILITY

SUMMARY: The U.S. Humane Slaughter Act (1958) requires that cattle held overnight in lairage have sufficient space to all lie down at the same time. Finished cattle weights have for some time continued to increase linearly. Observations, at night, were collected using video cameras at a U.S. commercial slaughter facility to determine the space required for *Bos taurus* finished cattle to be able to all lie down. Based on nighttime photographs, the following space requirements were determined to be required for fed cattle with average weights of a 544.31 kilogram (kg) (1200.0 pound (lb)) animal requires 1.86 square meter (m^2) (20.0 square foot (ft^2)), a 589.67 kg (1300.0 lb) animal requires 1.95 m^2 (21.0 ft^2), a 635.03 kg (1400.0 lb) animal requires 2.04 m^2 (22.0 ft^2), a 680.39 kg (1500.0 lb) animal requires 2.14 m^2 (23.0 ft^2), and a 725.75 kg (1600.0 lb) animal requires 2.23m^2 (24.0 ft^2) for all animals to be able to lie down at the same time.

Key cattle, lairage, stocking capacity, slaughter

INTRODUCTION

Commercial cattle slaughter facilities are required by 9 CFR 313.2 to allow cattle (e) “to have access to water in all the holding pens and, if held longer than 24 hours, access to feed. There shall be sufficient room in the holding pen for animals held overnight to lie down” (United States Department of Agriculture Food Safety and Inspection Service, 1987). The federal regulations provide no set space allowance requirement for cattle while being held at a slaughter facility during the day; adequate space allowance is usually determined by assessing the ability of cattle to access resources; e.g., water. The European Food Safety Authority (**EFSA**) states that, for livestock (sheep and goats), an adverse effect on transport welfare is a "lack of space to lie down all at the same time" and the UK Farm Animal Welfare Committee (**FAWC**) states "animals are required to have sufficient space to stand up, lie down and turn around without difficulty when penned" (European Food Safety Authority, 2011; World Organization For Animal Health (**OIE**), 2011; Farm Animal Welfare Committee, 2013). The United States livestock industry currently has standards for holding pen stocking capacity at slaughter facilities set forth in the Recommended Animal Handling Guidelines & Audit Guide published by the North American Meat Institute (**NAMI**) first established in 1991. Industry standards stated that plants should provide 1.86 square meter (m^2) per 544.31 kilogram (kg) animal in a holding pen during the day prior to the most recent 2017 revision of the guideline (Grandin and North American Meat Institute, 2013). This general guideline acknowledges that the cattle pen densities may vary by cattle size, weather conditions, and variation in holding times (Grandin and North American Meat Institute, 2017). Commercial harvest facilities have various ways to determine stocking densities of the holding pens that can include counting animals, visual observation or plant specific SOP for pen stocking density in different weather conditions; i.e., extreme heat, flooding, or snow. Third party animal welfare auditing services utilize the NAMI guidelines and audit tool to conduct welfare assessments. In the most recent revision, the audit tool was updated to included secondary criteria evaluating the density of the holding pens; i.e., if the cattle holding pens appear to be overcrowded and/or appear less than 75% full (Grandin and North American Meat Institute, 2017). However, this pen stocking density secondary criteria is not included in the core criteria for a slaughter facility to successfully pass an animal welfare industry audit. With increasing live cattle weights over the past several years there has been a recent push, within the United States cattle industry, to reevaluate the pen space allocation requirements for cattle held during the day, in particular, but also overnight at slaughter facilities (Grandin and North American Meat Institute, 2017). Colorado State University collaborated with NAMI, at NAMI's request, to conduct field observations of current commercial slaughter facility pen stocking densities. The purpose of this field observation was to evaluate current pen stocking densities at a finished steer and heifer commercial slaughter facility to determine space allocations needed for different average live weights of cattle in order for those cattle to lie down at the same time overnight. This field observation provides industry relevant information that slaughter facility personnel can readily apply to current animal handling programs.

MATERIALS AND METHODS

Ethical Statement

All animal measurements and observations that occurred were non-invasive. An exemption petition was filed and granted by the Colorado State University Animal Care and Use Committee for this field observation.

Facility and experimental animals.

This field observation was conducted at a commercial finished cattle slaughter facility in July of 2016, located in the Midwestern United States. The slaughter facility was a double shift plant operating two eight-hour production shifts (A and B shift), slaughtering approximately 5,000 cattle per day at a rate of approximately 350 head per hour when operating at normal commercial capacity. Cattle arrived at the processing facility on the research days and were assigned to overnight holding pens. All cattle selected for this field observation were steers or heifers of *Bos taurus* origin that were to be held overnight at the commercial slaughter facility. Cattle of *Bos indicus* or Holstein origin were not included in this field observation.

Measurements.

This field observation was conducted over a five-day period and 1,584 cattle were observed in 20 total pens (n = 1,584). Four pens were selected for adequate night lighting, distance away from unloading docks, and entrance to the slaughter facility to minimize disturbance of the cattle. Selected pens were uncovered and had concrete non-slip flooring and steel rails, 1.52 meters (m) in height, around the pen perimeter. Dimensions for pens selected to be used in the trial were measured before daily production began with a Komelon 6633 open reel fiberglass tape measure 300-feet (Komelon USA division, Waukesha, WI, USA), and then measured dimensions were compared to the slaughter facility blue prints. The average weights of the cattle and number of cattle per pen were obtained from the slaughter facility scale house. Average live weights of cattle were calculated by dividing the entire load net weight of the truck by the number of animals in the load.

Once the four selected overnight pens were filled with *Bos taurus* cattle arriving at the facility to be held overnight, two GoPro Hero 4+ (GoPro, San Mateo, CA, USA) cameras using 64 gigabyte 4K SD cards (Western Digital Technologies, Inc., Milpitas, CA, USA) were placed on the overhead catwalk railing that was approximately 0.61 m above the pen. The cameras were held in place with GoPro Jaw Clamps (GoPro, San Mateo, CA, USA). The cameras were placed in the GoPro clear plastic cases to protect against water damage from the sprinklers, which operated intermittently throughout the recording period in the holding pens. Each camera was able to collect data on two pens; four pens total were recorded each night for five consecutive nights. The cameras captured video and photographs of the cattle lying down between 0200 hour (h) and 0400 h each night. Video and photograph recording were initiated with a GoPro Smart Remote (GoPro, San Mateo, CA, USA) from 180 m away so that movement on the overhead catwalk did not disturb cattle. This prevented cattle from rising when the researcher walked on the catwalk. At least ten minutes of video footage and twenty photos were taken each night of each pen of cattle; these were timed and counted by the researcher at each collection. Once the recording period was complete, the researcher climbed the catwalk and observed the pens and documented the number of animals in each pen, how crowded the pens appeared, and the average live weight of the pen obtained from the facility scale house. Pens were categorized as 'under capacity', 'at capacity', and 'over capacity' (Figure 3.1). This was assessed by the amount of 'working space' available in the pen, square meters allotted per animal, average weight of cattle in the pen, and how easily the animals could move around in the pen. Working space was defined as the space needed for the plant employee to be able to efficiently and effectively empty the pen of cattle (Grandin and North American Meat Institute, 2017).

RESULTS AND DISCUSSION

As the weight of cattle increased, space allocation also needed to be increased to have allow space for all cattle to be able to lie down. Figure 3.1 illustrates different weight classes of cattle stocking densities and shows 1.86 m^2 per animal was not sufficient space for the heavier weight classes of cattle to be able to lie down all at the same time. The researcher and collaborating industry employees decided to evaluate cattle in 45.36 kg (100.0 pound (lb)) increments and add 0.093 m^2 (1.0 square feet (ft^2)) for every 45.36 kg over the 544.31 kg (1200.0 lb) base live weight. This allowed for easy calculations for pen stocking densities and for the researcher to evaluate if the 45.36 kg:0.093 m^2 was sufficient. The space allocation recommendations based off of the information gathered were as follows: a 544.31 kg (1200.0 lb) animal requires 1.86 m^2 (20.0 ft^2), a 589.67 kg (1300.0 lb) animal requires 1.95 m^2 (21.0 ft^2), a 635.03 kg (1400.0 lb) animal requires

$2.04\ m^2$ ($22.0\ ft^2$), a 680.39 kg (1500.0 lb) animal requires $2.14\ m^2$ ($23.0\ ft^2$), and a 725.75 kg (1600.0 lb) animal requires $2.23m^2$ ($24.0\ ft^2$).

Weeks (2008) stated there is very little current research on cattle pen density at lairage and theorized that this could be due to variability in live cattle weights and sizes. The individual animal size variation in the cattle industry has been a challenge for the slaughter industry for years. In the 2017 revision to the NAMI Recommended Animal Handling Guidelines & Audit Guide, a question assessing whether or not the holding pens were crowded was added. Additionally, space allowance guidelines within the guide were provided for larger cattle, whereas the guideline previously had a limited range of space allowances published.

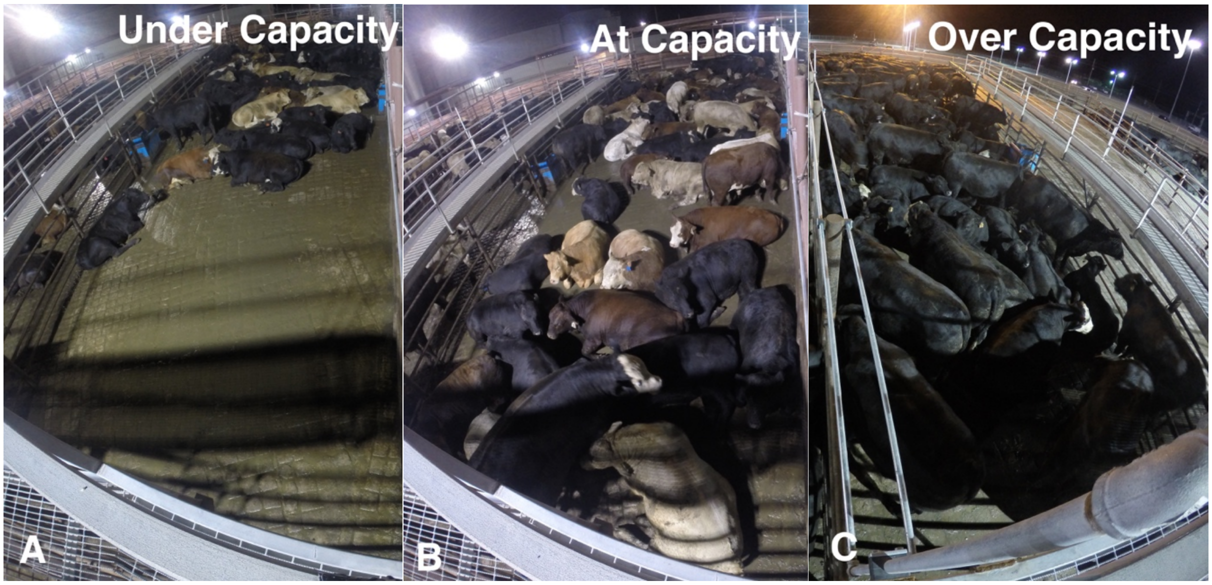
> "A rough guideline, 20 sq. feet ($1.87\ m^2$) should be allotted for each 1,200-pound (545 kg) steer or cow; 22 sq. feet ($2.04\ m^2$) should be allotted for each 1,400-pound (635 kg) steer; 23 sq. feet ($2.13\ m^2$) should be allotted for each 1,500-pound (680 kg) steer; 24 sq. feet ($2.22\ m^2$) should be allotted for each 1,600-pound (720 kg) steer (Grandin and North American Meat Institute, 2017)."

The language added in the NAMI Guide 2017 revision was based off of this observational study. Lairage time at the slaughter facility has potential to allow cattle to recover from dehydration, and reduce effects of transport. However, if lairage time lasts too long, it can also be detrimental to cattle recovering from feed and water restrictions (Jarvis et al., 1996). One of the contributing factors to cattle shrink is dehydration; providing water *ab libitum* allows water content in the muscle to be replenished and yield heavier carcasses (Hahn et al., 1978; Wythes et al., 1985; Grandin and Gallo, 2007). However, cattle need enough space, in the pens, to be able to perform these behaviors of lying down to rest and accessing water to rehydrate. It was also noted that, when cattle transition from standing up and lying down, this movement requires additional space (Weeks, 2008), emphasizing the importance of providing to cattle enough space to comfortably and easily lie down when held for extended periods of time; i.e., overnight. The United States livestock industry is making strides to address individual animal variability and pen stocking densities at the finished commercial slaughter facilities.

The purpose of this field observation was to evaluate current pen stocking densities at a fed steer and heifer commercial slaughter facility and determine if the industry recommended space allocations were sufficient for all cattle to lie down at the same time in the holding pens overnight as required by U.S. regulations. It was determined that as weight and size of cattle increased, pen space allocation needed to be increased. Approximately an additional 0.093 m^2 (1.0 ft^2) per 45.36 kg (100.0 lb) over the 544.31 kg (1200.0 lb) base live weight needs to be accounted for when calculating pens stocking densities at the slaughter facility. This calculation allows industry employees to be able to calculate the number of animals that can be held in a pen overnight, while also accounting for the average live weight of the cattle and the space needed for them to be able to lie down.

Figure 3.1

Different pen stocking capacities with cattle.



[A] Under Capacity: cattle pen dimensions of 234.58 m^2 for 88 animals allocating, 2.68 m^2 per animal. Average weight of the animal was 552.75 kg.

[B] At Capacity: Cattle pen dimensions of 185.81 m^2 for 99 animals allocating, 1.88 m^2 per animal. Average weight of the animal was 629.54 kg. All cattle could lie down at the same time.

[C] Over Capacity: Cattle pen dimensions of 195.88 m^2 for 108 animals, allocating 1.83 m^2 per animal. Average weight of the animal was 717.13 kg. Not sufficient space for all cattle to lie down at the same time.

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Chapter IV

PILOT STUDY: EFFECT OF CAPTIVE BOLT GUN LENGTH ON BRAIN TRAUMA AND POST-STUN HIND LIMB ACTIVITY IN FINISHED CATTLE.

SUMMARY: Hind limb kicking in properly stunned unconscious cattle is a safety hazard for employees. Three different captive bolt lengths of 15.2 cm (CON), 16.5 cm (MED), and 17.8 cm (LON) were evaluated for stunning effectiveness in a Jarvis USSS-1 pneumatic stunner. The air pressure setting was 200 to 210 psi for all captive bolts. All 45 test cattle were rendered unconscious with a single shot. There was a trend ($P = 0.06$) for less kicking to occur when the 16.5cm length bolt was used in the stunner. Visual appraisal of the brains on the split heads indicated that the shortest bolt caused the least amount of brain damage. The brainstems were intact for all cattle regardless of captive bolt treatment. Young fed English, Continental European, and Holstein steers and heifers can be effectively stunned without visible brainstem disruption. The cattle were held on a center track conveyor restrainer which may have had an effect on the angle of the shot.

INTRODUCTION

Ensuring animal welfare at the time of slaughter is an essential part of the commercial processing system. Additionally, in United States Department of Agriculture (USDA) inspected facilities, it is a federal requirement to render livestock unconscious before slaughter, as stated in U.S. Humane Slaughter Act 1958 and regulation 9 CFR 313.2 (e) (U.S. Code of Federal Regulations). In large commercial cattle slaughter facilities in the United States, pneumatically powered penetrating captive bolt guns are the primary stunning tool. The mode of action of a penetrating captive bolt is concussion and trauma to the brain. A metal rod is ejected from the muzzle of the captive bolt gun via a supply of pressurized air (Finnie, 1997). The bolt is propelled through the animal’s skull into the brain tissue, after which the bolt is retracted (Finnie, 1997). A secondary method of euthanasia is recommended to ensure the animal remains unconscious until death occurs; in cattle destined for slaughter, exsanguination is used (Leary et al., 2013).

Pneumatically powered captive bolt guns are powered by pressurized air and do not require the operator to reload a charge after each stun, thus often times making it the first choice of potential stunning tools for the fast processing speed of a large commercial slaughter facility. Additionally, captive bolt guns, when operated correctly and maintained, are effective at rendering cattle instantly unconscious without causing pain (Finnie, 1993; Grandin, 2009; Terlouw et al., 2016).

Most commercial fed slaughter facilities use a standard captive bolt length of 15.2 cm for Jarvis pneumatic stunners. In these stunners, only 9.02 cm of the bolt actually penetrates into the animal’s skull. Longer captive bolts are commercially available and some processing companies have started using them. The hypothesis is that the longer bolts may cause more brain damage, thus increasing effectiveness of the stun. Although some companies have been using the longer bolt, there is a need for research to determine the extent of the brain damage caused by these longer bolts. The second purpose if this pilot study was to determine if the length of the stunning bolt in a pneumatic captive-bolt stunner influences the frequency of hind limb kicking in cattle. Hind limb kicking is a safety hazard for commercial plant employees. Cattle that are properly stunned and unconscious may kick and still have hind limb movements (Terlouw et al., 2015).

MATERIALS AND METHODS

Ethical Statement

All animal measurements and observations occurred post-stunning at a commercial fed cattle slaughter facility and an exemption petition was filed and granted by the Colorado State University Animal Care and Use Committee for this study.

Facility and pre-selected animals

This pilot study was conducted at a commercial fed cattle slaughter facility in August of 2016, located in the western portion of the United States. The slaughter facility was a double shift plant operating two eight-hour shifts (A and B shift), slaughtering approximately 5,000 cattle per day at a rate of approximately 350 head per hour when operating at normal commercial fed facility capacity. Cattle arrived at the processing facility on the research days and were assigned to holding pens, where they remained until that lot of cattle was scheduled for slaughter. Ante-mortem inspection of the cattle was conducted by a USDA veterinarian before the animals were moved through the facility to the restrainer to be stunned. For ease of sampling, experimental cattle were chosen from lots that were to be slaughtered just before the facility production shift change; i.e., the end of A shift). All cattle selected for the study were steers or heifers of *Bos taurus* origin and cattle of *Bos indicus* origin were not included in this pilot study.

Treatment groups and experimental animal identification.

Three captive bolt length treatments were examined in the study: control bolt (CON), medium bolt (MED), or long bolt (LON), with lengths of 15.2 cm, 16.5 cm, and 17.8 cm, respectively, and which extended 9.02 cm, 10.32 cm, and 11.61 cm on average, respectively, from the pneumatic stunner. Captive bolt length treatments were blocked by day to ensure that the correct bolt length was used for each treatment collection (i.e., one of the three treatment bolt lengths was used on three separate days). Each captive bolt length was evaluated with fifteen animals with an approximately equal numbers of English, Continental European, and Holstein cattle (N = 45). Forty-five skulls were evaluated for brain damage assessment and 875 animals were observed for post-stun hind limb activity. Each collection day was one continuous 8 hr time block, on A shift, for each treatment.

On each collection day, cattle moved through the handling facilities following standard plant protocol. Cattle were moved from their lairage pen into the alleys and single-file chute that led to the center-track conveyor restrainer (Grandin, 2007). On each data collection day, cattle were stunned using the designated treatment bolt length. After stunning, the cattle were shackled, and conveyed onto the take away belt. As the take away belt moved the cattle forward, they were hoisted into a vertical position onto the slaughter rail.

All stunning procedures were conducted using a Jarvis USSS-1 (Jarvis Products Corp., Middletown, CT) captive bolt gun and Jarvis bolts. The captive bolt gun was tested at the beginning of each plant shift to ensure that the captive bolt gun was functioning correctly. Testing was performed by facility-trained plant personnel, using a Jarvis pneumatic test stand (Jarvis AST-101-Tester Tool, Jarvis Products, Corp., Middletown, CT) and the results were recorded in the plant's standard operating procedures documentation. All captive bolts were tested at 65 psi per plant protocol. The pneumatic captive bolt gun used in this pilot study included two cushion spacers, which added 0.64 to 0.84 cm of length to all bolts. For stunning, air pressure at the restrainer for the pneumatically powered captive bolt gun was set between 200 and 210 psi for all three pneumatic captive bolt lengths.

After exsanguination and hide-on carcass washing, researchers collected the facility-assigned age (i.e., over 30 months or under 30 months) based on dentition, the facility-assigned carcass identification, hide color, and the presence or absence of horns on the animal. After the skulls were separated from the carcass, an antimicrobial intervention was applied and the skulls were trimmed according to facility procedure. On the processing line, skulls were identified by the facility-assigned carcass ID and a captive bolt length ID on an index card (76.2 by 127.0 mm) that was covered on both sides with clear tape. This index card was placed in the nasal cavity of the skull while the skulls were still on the rail to avoid confusing the processing order. Since the index card was not visible once it was placed in the nasal cavity of the skull, heads were also marked with purple food grade dye (Grade and Yield Ink, Packers Chemical, Kieler, WI) across the occipital condyles to designate them for further scientific evaluation. Skulls were then removed from the conveyor belt for measurements and brain damage analysis.

Measurements

A GoPro Hero 4+ (GoPro, San Mateo, CA, USA), with a 64 gigabyte 4K SD card (Western Digital Technologies, Inc., Milpitas, CA, USA) and a battery extender, was positioned directly after the restrainer on a steel bar that was part of the facility structure overlooking the area from the take away belt up to the bleed rail stack line. It was placed at a high enough level so no employees in the area could obscure the camera's view.

The video was later evaluated by a trained researcher for breed type (English or Holstein), the number of kicks that each animal performed from the unshackled hind limb and if the animal demonstrated a righting reflex. The researcher was trained by reviewing several video clips and calibrating with the principal investigators and was blinded to captive bolt treatments. The observer began counting hind limb kicks once the entire animal was hanging perpendicular to the floor. There was a metal bar immediately before the start of the stack line (i.e., the queue of carcasses awaiting exsanguination); the observer stopped counting kicks when the carcass reached this bar. The total time observed per animal before reaching the stack was approximately ten to twenty seconds. There were 875 animals evaluated for the post-stun hind limb kicking measurements (CON, n = 217; MED, n = 264; LON, n = 394). Within the 875 sample, 146 were Holstein and 729 were English cattle (Table 4.2).

On-site facility brain trauma data collection

Skulls were removed from the conveyor belt and placed on a table to evaluate parameters related to stunning. Penetration depth (PD) of the bolt was measured by inserting a flexible ruler (Flexible Curve Ruler, Amazon.com Inc., Seattle, WA) into the stun hole in the skull and following the bolt tract with the ruler. A stunning accuracy score (AS) was determined with a plant-specific accuracy scoring system using a diagram that mimicked a "bullseye" held up at the recommended stunning location, the center representing an ideal stun. A score of 5, was the most accurate, was the innermost circle and descending scores of accuracy corresponded to increased circle size around the center circle, ending in a score of 1 for the outermost circle.

After conclusion of the first production shift, a plant employee split the experimental skulls with a brisket saw (Jarvis Model 444, Jarvis Products, Corp., Middletown, CT). The skulls were split down the captive bolt penetration hole along the sagittal plane of the skull. The skulls were not chilled before splitting and were stored in a container on the slaughter floor. Anecdotally, this methodology is commonly used by slaughter plants to train stunner employees on stunning placement. Once the skulls were split down the sagittal plane, the brain width, brain length, skull plate thickness, and area of damaged brain tissue were measured with a tape measure (Singer 218 60 inch) (Figure 4.1). The total length and width of the brain were measured, along with areas of the brain that showed trauma. Each skull was photographed before and after each split and evaluated in real time for gross brainstem disruption and damage.

Statistical Analysis

The individual animal was the experimental unit for all analyses. Continuous variables (PD, number of post-stun hind limb kicks, AS, and all head dimension measurements) were analyzed with models constructed in the MIXED procedure of SAS (Institute, 2008). The random term in the model was considered animal, and day and treatment were confounded, since each treatment was a separate day. Main effects included captive bolt length. For all data analysis, differences were considered significant if $P \leq 0.05$. All data are presented as average mean ± standard error.

RESULTS AND DISCUSSION

Post-stun Hind Limb Kicking

Post-stunning hind limb kicking tended to differ by captive bolt treatments (Table 4.2).

Stunning Characteristics

All animals were properly stunned and rendered unconscious during this pilot study. For stunning characteristics, accuracy of stunning ($P = 0.53$), penetration depth ($P = 0.41$), skull thickness ($P = 0.90$), brain length ($P = 0.60$), and brain width ($P = 0.90$) did not differ among the three captive bolt length treatments (Table 4.1).

Brain Damage Characteristics

The amount of damage to the brain tissue from the CON captive bolt was noteworthy compared to that resulting from the MED and LON bolts ($P < 0.03$). But, the amount of brain damage did not differ between the MED and LON captive bolt treatments. In this pilot study the brainstem was not disrupted in any of the captive bolt treatments (Figure 4.2).

Analysis of post-stunning hind limb activity, in this pilot study, showed that increasing the pneumatically powered penetrating captive bolt length did not necessarily decrease post-stun hind limb leg activity in cattle as hypothesized by some early adopters within the industry. The treatments only differed by two kicks and were not statistically different. Further studies to investigate post-stunning leg activity in cattle, at commercial slaughter facilities, are warranted to explore this outcome in more depth. Researchers observed that several animals also exhibited post-stunning forelimb activity. Additional studies should evaluate post-stunning forelimb kicking as well as hind limb kicking. The hind limbs and forelimbs of the cattle were observed to have different kicking rates. Employee safety is a concern at the shackle conveyor belt and exsanguination positions. The employees cannot process the carcass until the post-stun leg activity has stopped. If kicking frequency could be reduced by changing bolt length, this would provide another safety measure for workers in that area.

Results from this pilot study indicated that all captive bolt treatment lengths resulted in damage to brain tissue, causing cerebra-cortical damage rendering the cattle unconscious. The standard width of a Jarvis USSS-1 stunner captive bolt, for all bolt lengths is 1.59 cm. This width is considered ideal to reduce risk of bolts snapping/breaking if they were manufactured any thinner. Although not evaluated in this study, assessing penetration angle of the captive bolt tract would have allowed researchers to see if bolt length had an effect on the angle at which the pneumatic stunner was fired. Industry professionals suggested that using a longer bolt could cause an increased amount of brain damage and decrease the chance of the cattle returning to sensibility. The repercussions of ineffective initial stuns from a regulatory standpoint, as well as from the animal welfare perspective, are critical and the commercial slaughter industry will support potential methods to reduce the chances of this event occurring. Although no animals returned to consciousness in this pilot study, more research is required to investigate the process of nerve death and the rate of post-stunning leg activity in cattle at commercial slaughter facilities.

There was no disruption to the pons, midbrain, or medulla oblongata, referred to as the "brainstem", using any captive bolt length in this pilot study as determined by visual observation of the brain within split skulls. Previous studies indicated that brain stem disruption was present after captive bolt stunning (Gilliam et al., 2012). However, Gilliam et al. (2012) conducted their study in a controlled laboratory setting with a hand-held captive bolt gun on bovine cadaver skulls. The hand-held Model Jarvis Power Actuated Stunner with the heavy-duty bolt extends 12.065 cm and the Jarvis USSS-1 stunner pneumatic captive bolt extends 9.017 cm with the control bolt. This difference in length likely impacts the locations of brain damage. Splitting skulls without a 12-24 hr chill time made the damage assessment of the brain tissue challenging. Without the 12-24 hr chill time, the brain tissue was very gelatinous and did not hold true to its shape, making it difficult to assess damage that could be specifically attributed to the bolts being assessed in this study. A 12-24 hr chill time is recommended before splitting skulls, along with using a band saw instead of a brisket saw for more accurate damage assessment. If further studies were to be conducted, researchers would use a brain diagram on transparent plastic to overlay on the split brain to assess damage to specific brain structures and regions.

There was some concern that an increased bolt length may lead to stunner employee fatigue due to increased air pressure for the LON treatment (increased air pressure was applied to all treatments in this study, not just the LON treatment). To assess worker fatigue, accuracy scores for stunning were assessed for 15 skulls, per captive bolt treatment; these skulls were collected at the end of the 8 hr work shift. The assumption was if the knocker became fatigued, his accuracy score could decrease. However, average accuracy scores did not differ between treatments. This seems to suggest that, in this study, the longer bolts did not have an effect on worker accuracy of stunning cattle in commercial slaughter facility conditions.

Table 4.1 Main effects of captive bolt length on brain trauma measurements postmortem activity score (N=45).

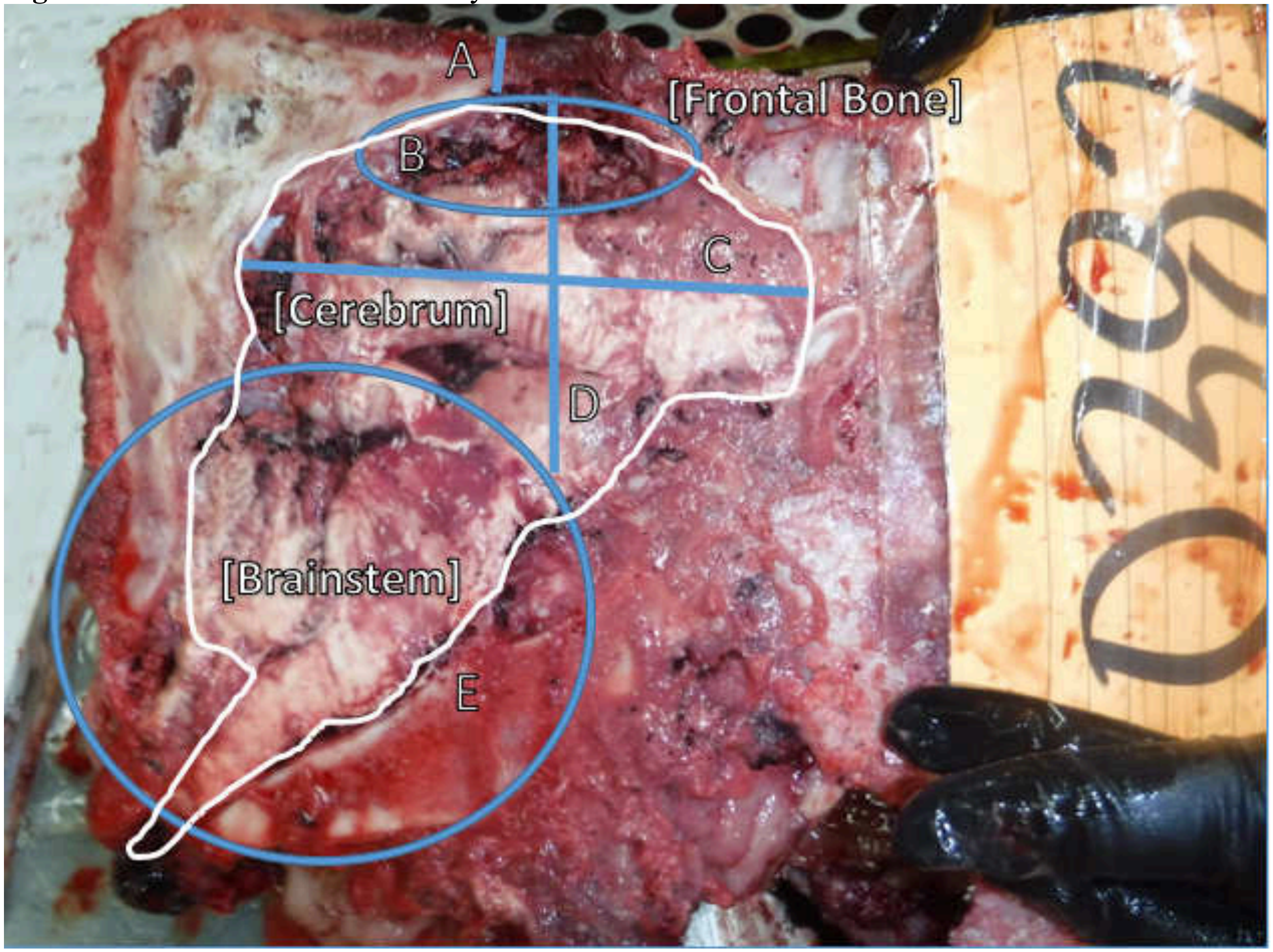
	Captive bolt treatment[1]				
Measurement	CONTROL n = 15	MEDIUM n = 15	LONG n = 15	S.E.	*P* - value
Accuracy of stunning*	4	4	4	0.2	0.53
Penetration depth, cm	5.9	6.4	6.5	0.6	0.41
Skull thickness, cm	2.0	2.0	1.9	0.2	0.9
Brain length, cm	5.6	1.3	3.1	2.9	0.6
Brain width, cm	9.6	9.8	9.7	0.5	0.9
Brain damage, cm	2.4^a	3.1^b	3.5^b	0.3	<0.03

* Accuracy of stunning was evaluated using facility assessment tool.

[1] Bolt treatment CONTROL denotes the standard bolt length, MEDIUM is 1.27cm extended in length, and LONG is 2.54 cm extended in length.

[2] Means with different superscripts (a,b) differ ($P < 0.05$).

Figure 4.1 Bovine brain trauma analysis



^{A} Skull thickness, cm
^{B} Area of brain that displayed damage, cm
^{C} Brain length, cm
^{D} Brain width, cm
^{E} Brainstem with no visible disruption

Table 4.2 Main effects of captive bolt length on postmortem activity score (N = 875).

	Captive bolt treatment[1]				
Measurement	CONTROL n = 217	MEDIUM n = 264	LONG n = 394	S.E.	*P* - value
Kicks, number	7.0	5.0	7.0	0.4	0.06

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[1] Bolt treatment CONTROL denotes the standard bolt length, MEDIUM is 1.27cm extended in length, and LONG is 2.54 cm extended in length.

[2] Means with different superscripts (a,b) differ ($P < 0.05$).

Figure 4.2 Bovine brain trauma by captive bolt length treatment

[A] Control captive bolt length (15.2 cm) bovine brain tissue damage
[B] Medium captive bolt length (16.5 cm) bovine brain tissue damage
[C] Long captive bolt length (17.8 cm) bovine brain tissue damage

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Chapter V

CARCASS BRUISING LOCATION AND BRUISE TRIM LOSS IN FINISHED STEERS, COWS, AND BULLS AT FIVE COMMERCIAL SLAUGHTER FACILITIES

SUMMARY: Determining the location of, and investigating possible causes for, bruising in beef carcasses is critical for addressing animal welfare concerns in the livestock industry. This study was conducted in five commercial beef slaughter facilities in multiple regions of the United States that slaughter finished steers/heifers, as well as culled cows and bulls. At each plant, the animals were chosen randomly from each utilized trailer compartment, to select at least one animal from each compartment. In total, approximately 50 animals were selected each night, providing 150 selected animals over the three days of sampling at each facility. Individual carcasses were followed through the slaughtering process and were evaluated before the carcass was split for: presence/absence of bruising, bruise location, and weight of bruised meat from each carcass that was removed during trimming. Overall, 28.1% of carcasses were visibly bruised. Regions of the carcass that had the highest bruise incidence were the round, rib, and loin beef primal cuts, respectively. However, some carcasses had deep tissue bruises that were not visible on the surface of the carcass, but trim loss was collected once these bruises were exposed. Such trimmings averaged 1.0 kg per carcass. Cattle shipped in the top deck trailer compartment were less likely to be bruised compared to cattle shipped in the belly compartment of the trailer ($P = 0.03$). Reduction of bruising enhances animal handling and reduction in trim loss adds economic efficiency along the entire beef supply chain.

INTRODUCTION

There are several factors that affect cattle well-being during commercial transport to slaughter facilities. These factors can include human-related factors such as the driving experience of the truck driver. Transportation factors, such as extreme ambient temperature, trailer type, trailer noise and vibration, travel distance road condition, total journey time, space allocation, and vehicle design could also impact cattle well-being during transport. Animal handling and deprivation of water and feed can also be stressors the cattle may be exposed to in commercial hauls to slaughter facilities (Dodt et al., 1979; Broom, 2003; Fazio and Ferlazzo, 2003; Minka and Ayo, 2009; Huertas et al., 2010; González et al., 2012; Gonzalez et al., 2012b; Mendonça et al., 2018) which all can impact animal well-being.

Broom (2000) states that bruises, carcass quality, mortality, and injuries can all be used as livestock welfare indicators to assess handling and transport. Mortality records can provide information on livestock welfare during the journey but bruises, injuries, blemishes, carcass defects give information about the livestock welfare during handling, and lairage (Broom, 2000). Bruises can cause economic loss in the beef industry and are indicators of potential animal welfare concerns during pre-slaughter animal handling management (Jarvis et al., 1995).

A previous study by Lee et al. (2017b) observed finished cattle unloading at slaughter facilities. The Lee et al (2017) study provided valuable and current information on bruising prevalence by cattle lot but the study did not examine the experience and bruising of individual animals nor provide an estimate of the actual yield loss due to bruising

The current study expands on the Lee et al. (2017b) study by evaluating bruising on an individual animal basis. This study provides new insights into bruising incidence rates, trailer compartment differences, bruise trim incidence rates, cattle trailer operator experience, cattle body condition score, and cattle sex class differences within the cull cattle industry. This current study includes individual animal tie back from cattle unloading to carcass bruise trim removal, allowing in depth assessment of bruises and their impact on animal welfare and the economic impacts on the cattle industry. This study was aimed to assess trailer unloading and trailer compartment as quality control points for bruising in the livestock supply chain.

MATERIALS AND METHODS

Ethical Statement

All animal measurements and observations that occurred at the commercial slaughter facilities were non-invasive and an exemption petition was filed and granted by the Colorado State University Animal Care and Use Committee for this study. This study was a collaborative effort with the slaughter facilities and Colorado State University.

Facility and pre-selected animals

This study was conducted at five commercial cattle slaughter facilities that process culled cows and bulls, and more youthful fed steers and heifers, from October 2017 to March 2018, located in various regions of the United States. Data were collected for one week at each facility, for a total of five weeks. The slaughter facilities were single production shift plants, operating one 9 hour shift and slaughtering approximately 1,100 to 1,950 cattle per day at a rate of approximately 140 to 280 head per hour when operating at normal facility capacity. Cattle arrived at each processing facility on the research days and were randomly selected coming off of trailers during unloading upon arrival at the slaughter facility, from each trailer compartment, for individual animal identification. All cattle selected for the study were culled cows or bulls, or more youthful fed steers or heifers of *Bos taurus* and Holstein origin. Cattle of *Bos indicus* origin were not included in this study.

Ante-mortem pre-selected animal identification

The cattle arrival schedule was obtained and reviewed for data collection each day at each individual facility. After reviewing the schedule, researchers determined which trailer loads of cattle would be processed the following day (some loads were slaughtered during the current day and some were held overnight to be slaughtered the following day). This determination was important because observers had to be present on the slaughter floor to record postmortem carcass information on individual animals. From this set of cattle trailers, ten were selected for individual animal sampling. For three consecutive nights at each facility, between 1800 h and 400 h, the selected trucks followed standard plant procedure by checking in at the office, aligning with and parking at the designated loading dock, and waiting for plant employee instructions for commencing unloading. For each selected truck, five animals were individually marked for postmortem data collection. All sample animals were selected from each utilized trailer compartment (Figure 5.1; (Figure 5.2), and at least one animal from each compartment. In total, approximately 50 animals were marked each night providing 150 marked animals over the three days of sampling at each facility. These marked animals at trailer unloading at each facility were the “pre-selected” animals.

Four GoPro Hero 5 Black Series cameras (GoPro, San Mateo, CA, USA) fitted with 64 gigabyte 4K SD cards (Western Digital Technologies, Inc., Milpitas, CA, USA) were used each night to record the unloading process for each of the pre-selected trailers. Two cameras were placed on each unloading dock (the number of unloading docks was plant dependent), with GoPro Jaw Clamps (GoPro, San Mateo, CA, USA) to capture two different views: (1) the exit and inside of the trailer and (2) the observer marking the cattle for postmortem evaluation and cattle height. The exact camera location varied by facility and was determined during project preparation. Three pieces of yellow florescent tape were placed on the side of the unloading dock (either the facility wall or a metal support structure) at 1.5 meters (5 feet), 1.8 meters (6 feet) and 2.1 meters (7 feet) to estimate cattle height as the cattle exited the trailer.

Cattle were marked individually, with a curly Q pattern on the dorsal topline (Figure 5.3) using purple, red, orange, and yellow food grade dye (Grade and Yield Ink, Packers Chemical, Kieler, WI) when a portion of white in the hair coat was visible. The food grade dye was applied with RL Flo-Master 1-Gallon Sprayers (RL Flo-Master, Lowell, MI, USA) (Figure 5.4). Florescent pink, orange, yellow, blue or green Estrotect Heat Detector patches (Estrotect Heat Detector, Rockway Inc., Spring Valley, WI, USA)(Figure 5.5) were used with Kamar Adhesive (Kamar Adhesive, Kamar Products Inc., Zionsville, IN, USA) and florescent pink, orange, yellow, blue or green All Weather Paint Stiks (All Weather Paint Stik, La-Co Industries, Elk Grove Village, IL, USA) when a portion of white in the cattle's hair coat was not visible. The All Weather Paint Sticks were attached to U.S. Whip Grey Heavy-Duty Sorting poles (Sorting Poles, U.S. Whip, Miami, OK, USA) to extend the observer's reach to mark the cattle exiting the trailer.

Observers were always behind gates for personal protection and wore proper personal protective equipment (PPE). Letters of Guarantee (LOGs) and material safety data sheets (MSDS records) were obtained for all dyes and patches used since all animals were entering food production facilities. The Estrotect Heat Detectors required Kamar adhesive glue, due to the low temperature outside, to be applied with a back tagging stick developed by facility personnel. Before initiating data collection, each trailer compartment was assigned a food grade dye or Estrotect patch color that would remain constant for all trucks. The compartments identified included the nose, top deck, belly, and tail for potbelly style trailers, and the front, middle, and tail for straight style trailers. The first observer marked the cattle as they exited the trailer on the dorsal topline, with the designated color per compartment and with the curly Q pattern or color patch. The second observer recorded the style of trailer, trailer compartment of origin, number of non-ambulatory animals (downers), number of animals dead on arrival (DOA), animal sex class, color of dye/patch used, trailer appointment number, dock of unloading, total number of animals in the trailer, and hide color of the animal. The third observer recorded the trailer model make and number, trailer style, trailer appointment number, distance travelled (km/miles), and driver experience (years). The fourth observer operated the GoPro Hero 5 Black cameras and made sure both cameras were recording video during each unloading event on each dock for analysis at a later date by a trained observer.

Live Animal Evaluations

Several attributes of each marked animal were recorded after they exited the trailer. One observer recorded back tag number, ear tag number, hide color, dye or patch color, animal sex class, and appointment number for the marked cattle. Additionally, the observer evaluated body condition, hock lesions, mobility and udder condition (for cows only) on the marked cattle. Body condition score for finished cattle was evaluated using the scale 1 to 9 where 1 was the thinnest animal and 9 was the most finished animal (Eversole et al., 2005). Body condition score for dairy cattle was evaluated using the scale 1 to 5 where 1 was the thinnest animal and 5 was the most muscular/fat animal (Kellogg, 2010). Hock lesions were scored using the scale by Fulwider et al. (2007) (0-3 scale, 0 = no hair loss or swelling; 3 = severe swelling). Cattle mobility was assessed once the cattle had exited the trailer using the North American Meat Institute Mobility Scoring System (NAMI; 1 – 4 scale, 1 = normal, 4 = extremely reluctant to move) (North American Meat Institute, 2016; Edwards-Callaway et al., 2017). The udder for the cows was scored by assessment of whether or not the udder impeded the cow's movement due to its size or not. After the cattle were unloaded, they were moved to a designated rest pen by plant employees where they were held overnight. Cattle remained in these pens until that lot of cattle was scheduled for slaughter.

Ante-mortem inspection of the cattle was conducted by a USDA veterinarian before the animals were moved through the facility to the restrainer to be stunned.

Postmortem pre-selected animal identification

The following morning after cattle had been randomly selected, recorded, and evaluated, the same cattle were further evaluated as carcasses on the facility slaughter floor. All cattle were stunned using a pneumatic stunning device, one facility had a knock box, but all other facilities utilized a center track restrainer. Two observers were positioned immediately after exsanguination and before head removal on the slaughter floor. These observers recorded color of animal hide, color of dye or patch used, facility assigned carcass identification and sex class of the animal after they had been exsanguinated. One of the observers placed a “CSU Bruising Study”, laminated tag with a rubber band on the leading ear of each animal that had been marked on the dorsal topline the previous night; color of the tag was predetermined depending on each facility’s tagging system. This CSU tag was the signal for the next observer, at the first hind limb hang off, to place another CSU tag on the trolley supporting the leading hind leg of the carcass. The trolley tag had to be placed in between the “eye” of the hook and the portion of the trolley that touches the rail so that the rubber band remained intact throughout processing. Once the head was removed from the carcass, the first CSU tag was discarded. The second CSU tag on the trolley of the hind limb, of the pre-selected carcasses, served as the signal to the facility employees to not trim any bruises off of the carcass until that carcass reached the “final trim” rail before the entrance to the cooler. This required coordination and communication of the facility supervisors, observers, and facility employees and sometimes due to carcass contamination as some bruises were trimmed off before observers could document and collect them.

Bruise Visual Assessment

Bruise location and color were recorded for the pre-selected carcasses and hundreds of other processed carcasses at each facility. One observer was positioned to evaluate bruises on the carcasses before the carcasses were split and after the hide was pulled. A GoPro Hero 5 Black camera was positioned to record carcasses as they passed by the observer. The video from this camera was collected for additional analysis after the sampling at the plant was completed. The same observer visually scored bruises at every facility in this study. A modified version of the Strappini et al. (2012a) diagram was used to record carcass identification, bruise color, and location of the bruises for each carcass. A bruise color scale from 1 to 4 (1 (bright red), 2 (dark red/purple), 3 (light red/purple/green, watery consistency), 4 (rusty light orange)) was utilized in each bruise assessment (Langlois and Gresham, 1991) From their position, the observer was only able to asses bruises visible on the carcass surface, and not deep tissue bruises that were not visible on the surface. Finally, this observer attached two laminated CSU tags that had been sterilized at a hot water station to either side of the carcass spine using shroud pins. These tags were in addition to the CSU tag on the trolley and allowed observers on the final trim rail and cooler to identify pre-selected carcasses more easily.

Bruise Trim Assessment

Two observers collected bruise trimmings from the pre-selected carcasses. They were positioned at the final trim rail, where carcasses were assessed, and any remaining contamination or damage was removed, to collect bruise trimmings (portions of the carcass trimmed off) from the pre-selected marked carcasses identified with a CSU trolley tag and another CSU tag on each side. Bruise trim was defined as a special type of hematoma that had a focal point of discoloration caused by blood collecting under the surface of the epidermis, that could be seen with the naked eye, that occurred due to trauma to the body antemortem (Marshall, 1977; Capper, 2001; Langlois, 2007; Pilling et al., 2010). One observer collected the bruise trim with the assistance of a designated facility employee, and the other observer recorded the data. Observers collected bruise trim from the pre-selected carcass which had been marked with a CSU tag on the trolley and CSU tags on either side of the carcass. Observers pre-labeled clear plastic liver bags with individual IDs for ease of data collection for each collection day. Observers recorded the carcass ID, liver bag ID, and bruise trim weight once bruise trimmings were collected from each marked pre-selected carcass. Trimmings from both visible and deep tissue bruises were collected. Facility employees indicated to observers that light pink hues on portions of the carcasses indicated deep tissue bruising that visually did not appear as a bruise on the surface. Once the bruise trimmings were collected, the liver bag was sealed and placed in a large bucket on wheels for weighing.

Cooler Assessment

Once the carcasses were in the cooler, a designated plant employee recorded further postmortem information on the pre-selected carcasses marked with CSU tags. Between 12 and 24 hours postmortem, dependent on facility chilling procedure and sex class of carcass (i.e., carcass of steer, heifer, cow, bull). The designated employee recorded the hot carcass weight and carcass ID while also evaluating the carcasses for round damage, loin damage, window bruises, arthritis, water pockets, abscesses, and whether the carcass had been “downgraded” in monetary value (Table 5.1).

Unloading Video Analysis

After completing data collection at each facility, the video footage of unloading was assessed. The video observer recorded: trailer type, trailer compartment unloaded, dye/patch color used, hide color, back tag number, ear tag number, presence of horns, whether or not a traumatic event occurred at unloading, trauma location to the body, whether the animal was scraped, two or more animals jammed at the trailer exit point, and approximate cattle height (Table 5.2). A "traumatic event" was defined as any time the animal made contact with the trailer or jammed with another animal during unloading (Lee et al., 2017b).

Statistical Analysis

Data were analyzed using the software R (R Core Team (2016) with $\alpha = 0.05$. Analysis included summary statistics, calculation of used confidence intervals, logistic regression, and chi-square tests to draw inferences from the sample data. Facilities were analyzed separately and also combined. Data were analyzed to evaluate differences in bruising incidence rates, trailer compartment differences, bruise trim incidence rates, cattle trailer operator experience, cattle body condition score, and cattle sex class differences.

RESULTS AND DISCUSSION

Ante-mortem factors and bruise prevalence

Of the pre-selected animals, 23.76% were beef breed type cattle and 76.24% were dairy breed type cattle (Table 5.3). When the pre-selected animals are categorized by sex class, 2.13% were bulls, 32.30% were cows, and 65.58% were finished steers/heifers (Table 5.4). A total of 3.6% of the pre-selected animals had horns (Table 5.5) and 3.6% of the pre-selected animals experienced a traumatic event at unloading at the slaughter facility (Table 5.6).

We found visible bruising prevalence varied across different cattle characteristics. Steers/heifers were less likely to be bruised than cows ($P = 0.001$), however there was not a statistically significant relationship between steers/heifers and bulls ($P = 0.07$) or bulls and cows ($P = 0.56$). Of the pre-selected cattle observed at all the facilities 48.5% of cattle derived from auction barns were bruised (95% CI: 42.54, 54.46; n = 270) and 36.90% of cattle not derived from auction barn origin were bruised (95% CI: 31.92, 41.88; n = 306) (Table 5.7). Using logistic regression, we found a statistically significant relationship (*P* = 0.001) between body condition score (BCS) and bruising incidence at Plant 5. For this plant, as BCS increased the bruising incidence rate decreased. We did not find statistically significant relationships between BCS and bruising incidence at any other observed facility (Table 5.8).

Cattle Trailer Operators

Cattle trailer operator experience was assessed, along with the distance that cattle traveled. For all cattle trailer operators observed, 11.8% had less than two years of driving experience, 38.2% had between two and ten years of driving experience, and 49.3% had more than ten years of cattle trailer driving experience (Table 5.9). Evaluation of cattle hauling distances showed that 5.8% were less than 161 km, 49% were between 161 km and 402 km, and 45.2% of hauls were greater than 402 km (Table 5.10). Logistic regression was used to analyze the impact of cattle trailer operator experience (years) on cattle bruising incidence; results suggested no statistical relationship (*P* = 0.14) between these two factors. The minimum amount of driving experience was one week and the maximum amount of driving experience was 45 years (SD = 11.64 years).

Trailers

For all cattle trailers observed, 42.3% of cattle that arrived in potbelly trailers were bruised and 50.0% of cattle from straight trailers were bruised (Table 5.11). However, data were recorded from fewer straight style trailers compared to potbelly style trailers in this study. Bruising incidence by trailer compartment is provided in Table 5.12. The potbelly style compartment with the highest bruising incidence was the small upper compartment above the entry and exit of the trailer (dog house). The potbelly style compartment with the lowest bruising incidence rate was the top deck. Statistical differences between the top deck and belly compartments of the trailer in bruising incidence were detected. Complete results are given in Table 5.12. Cattle transported in the top deck compartment of trailers were less likely to be bruised compared to cattle that were transported in the belly compartment of trailers ($P = 0.03$).

Bruises

Differences in bruise incidence among cattle sex class and patterns in carcass bruising locations were evaluated. The regions with the highest bruising incidence were the loin, hip, and round regions (Table 5.13). For all cow, bull, and fed steer/heifer carcasses observed, 28.1% were visibly bruised (Table 5.14; Figure 5.6). When the subset of pre-selected carcasses was categorized by sex class, 52.8% of cow carcasses were visibly bruised (95% CI: 45.76, 59.84; n = 193), 64.3% of bull carcasses were visibly bruised, and 36.5% of fed steer/heifer carcasses were visibly bruised (95% CI: 31.65, 41.35; n = 378) (Table 5.15).

When pre-selected carcasses were categorized by breed type, 52.1% of beef type cattle were bruised (95% CI: 43.82, 60.38; n = 140) and 39.6% of dairy type cattle were bruised (95% CI: 35.06, 44.14; n = 445) (Table 5.16). For all bruises observed, at all the slaughter facilities, 12.7% were bright red, 71.4% were dark red/purple, 15.7% were light red/purple/green with watery consistency, and 0.20% were rusty light orange in color (Table 5.17).

Bruise Trim Loss

Pre-selected carcasses were visually evaluated for bruises, and then bruise trimmings were collected from those carcasses. However, some bruises were removed at the “final trim” (the location of final carcass inspection by USDA-FSIS inspectors) rail that were not visible during bruise assessment before carcasses were split into sides (Table 5.18).

Bruise trimmings loss occurred on 56.4% of the pre-selected carcasses. Of the pre-selected carcasses that were scored as visibly bruised, 76.5% also generated bruise trimmings losses. Moreover, 41.7% of carcasses that did not have visible bruising also generated bruise trimmings losses as well.

For all cow, bull, and finished steer/heifer pre-selected carcasses, there was a downgrading incidence of 1.7% (Table 5.19), window bruising incidence of 11.5% (Table 5.20), and an average bruise trimmings weight of 1.0 kg (Table 5.21) among all slaughter facilities. Of the pre-selected cow carcasses, 72.9% generated bruise trimmings losses (95% CI: 66.53, 79.47; n = 181), 76.9% of pre-selected bull carcasses generated bruise trimming losses (95% CI: 54.12, 99.88; n = 13), and 49.8% of pre-selected fed steer/heifer carcasses generated bruise trimming losses (95% CI: 45.16, 54.84; n = 410) (Table 5.22). The most heavily trimmed regions of the carcass, due to bruising, were the rib, loin, hip, and round regions (Table 5.23) (Figure 5.7).

Of trailers observed in this study, 3.6% of the individual pre-selected animals experienced a traumatic event at unloading at the slaughter facility. Lee et al. (2017a) reported 20.4% of finished cattle, on a lot basis experienced a traumatic event at unloading. The Lee et al. (2017a) study evaluated cattle on a lot basis and observed only finished cattle, compared to the current study that evaluated cattle on an individual animal basis and observed cows, bulls, and finished steers/heifers. The cattle evaluated in this study were 1.52 m in height or shorter at the shoulder, as approximated by the markers added to the trailer unloading docks used during the recording of unloading. These differences in methodology may explain differences in traumatic event incidence rates at trailer unloading at the slaughter facility. The low rate of traumatic events at unloading indicated that other points in the livestock supply chain may be critical control points in need of investigation that are contributing to cattle bruising.

The horn prevalence rate, for pre-selected carcasses, was lower than the prevalence rates reported in NBQA-2016 (Harris et al. (2017) and Market Cow and Bull Beef Quality Audit 2007 Nicholson (2008). Meischke et al. (1974) and Shaw et al. (1976) observed that carcasses from horned animals generated twice as much trimmings as carcasses from hornless cattle. Of the pre-selected cattle observed in the present study, at all the facilities, 48.5% of cattle derived from auction barns were bruised and 36.9% of cattle from not derived from auction barn origin were bruised. McNally and Warriss (1996) stated that cattle origin can play a role in bruising incidence as it was observed that cattle from live auctions had more bruises and rejected meat than cattle from farms and dealers. Animals that travel through multiple points within the livestock supply chain may be more at risk for bruising.

The statistical relationship between cattle BCS and bruising incidence ($P = 0.001$) at Plant 5 showed that, as the BCS score increased (cattle body condition improved), carcass bruising incidence decreased. Location of the injury can affect the amount of hemoglobin released from vessels. For instance, if the area is low in connective tissue and high in adipose tissue, and very vascular, there can be a larger amount of blood released (Johnson, 1990; Vanezis, 2001b). The depth of the injury can also affect the time that it takes for the bruise to appear on the surface of the dermis; superficial bruises can appear almost immediately, while deep tissue bruises can take hours to appear (or not appear at all) on the surface due to the body initiating the inflammatory response (Langlois and Gresham, 1991). This could indicate that when body condition score improves that cattle may not be as susceptible to bruising.

Cattle trailer hauling distances ranged from 96.56 km to 1,367.94 km. There appeared to be more cattle trailer operators with moderate to extensive experience in this current study compared to inexperienced cattle trailer operators. Gonzalez et al (2012, a, b) found that the proportion of compromised animals and "shrink" decreased as the driver's experience increased, however the current study did not find a statistically significant relationship between cattle trailer operator experience and visible carcass bruising incidence ($P = 0.14$).

Gonzalez et al. (2012c) concluded that most cattle appear to be transported in the largest trailer compartments (e.g., the top deck and lower deck) and that more driving experience improved animal well-being outcomes during cattle transport. In the present study, cattle shipped in the top deck compartment of trailers were less likely to be bruised than cattle in the belly compartment. There were no differences in bruising incidence between other trailer compartments, with the exception that animals shipped in the top deck were less likely to be bruised than those in the tail.

The National Beef Quality Audit 2016 (NBQA-2016) for fed cattle documented that 38.8% of observed U.S. steer and heifer carcasses were bruised, 64.1% of observed U.S. cow carcasses were bruised, and 42.9% of observed U.S. bull carcasses were bruised (Eastwood et al., 2017; Harris et al., 2017). The overall visible bruising incidence rate, for the present study, was 28.1% and, when the subset of pre-selected carcasses was categorized by sex class, 52.8% of the cow carcasses were visibly bruised, 64.3% of the bull carcasses were visibly bruised, and 36.5% of the finished steer/heifer carcasses were visibly bruised. This current study had similar findings to the National Beef Quality Audit 2016 for bruising incidence rate for steer/heifer carcasses, a lower bruise incidence rate for cow carcasses, and a higher bruise incidence rate for bull carcasses.

During the study, facility employees showed the researchers the light pink hues on the carcasses that indicated bruises beneath the surface. Carcasses that had these light pink hues, not scored as a bruise, were trimmed. Bruise trimmings losses occurred on 56.4% of pre-selected carcasses. Of pre-selected carcasses that were evaluated as visibly bruised, 76.5% also generated bruise trimmings losses. However, 41.7% of carcasses that did not have visible bruising did experience bruise trim loss as well. Bulls had the highest bruise trim incidence rate compared to cows, followed by fed steers/heifers and this could be due to the sample size in the study. The deep tissue bruises, that are not visible on the surface for visual assessment, create a bruise a trim loss incidence rate of 56.4% which is higher than the visible bruising incidence rate of 28.1%. This indicates that the industry could potentially be missing bruises present at the time of harvest that are not visible on the surface of the carcass.

Visual assessments have long been the most practical and easiest method for bruise identification and aging of bruises (Trujillo et al., 1996). Hamdy et al. (1957a) stated that, on slaughtered animals, the method most used was 'gross observation and color changes' to assess bruises. Visual bruise assessment and bruise trimmings incidence rate indicated that visual assessment of bruise presence might not be the most accurate method. More objective methods considered for bruise assessment include colorimetry, reflectance spectrophotometry, concentration measurements of hemoglobin and bilirubin in vivo, and histology (Hughes et al., 2004a; Langlois, 2007). As the methodology is developed for these alternate assessment options, the application to industry will be possible in the future.

Perception of color, such as green, blue, yellow, purple, black, orange, brown or red, does not indicate age of a bruise (Hamdy et al., 1957c; McCausland and Dougherty, 1978; Langlois and Gresham, 1991; Langlois, 2007). However, a general consensus seems to exist on the progression of the color changes of a bruise—but the exact time periods that match these color changes are debated (Langlois and Gresham, 1991). The generally accepted color cycle of a bruise is that red, purple and blue are the early appearing colors, green appears after red, blue, and purple (between days 4-7), and yellow appears after green (not until at least day 7) (Langlois and Gresham, 1991). The majority of bruises observed in the present study were dark red/purple which would be in the category of the 'early appearing' bruise colors. Which would indicate the bruises occur while the animals are in the livestock supply chain that ends at the slaughter facility. In the present study, the same observer was present at each slaughter facility to evaluate bruise color and bruise presence. Color perception can vary based on an individual's age and Strappini

Bruise trim weights in an Australia study ranged from 0.68 kg to 7.35 kg per carcass (Meischke et al., 1974) and average bruise trimmings weight was 1.0 kg. It has been acknowledged that any bruised tissue trimmed from a beef carcass reduces value and yield from possible downgrading for the producers and processors in the livestock industry (Warriss, 1990; McNally and Warriss, 1996).

In this study, it was determined that visual bruising assessment may not be the most accurate method to determine bruising incidence rate. Deep tissue bruises are difficult to detect with visual assessment on the slaughter floor. Assessing accuracy of visual appraisal of bruise carcass trimmings to calculate the potential yield loss to the industry can provide an accurate benchmark of the economic impact of bruises in the livestock industry. Estimations of bruise trimmings using visual methods requires training of the observer and can be difficult. The scientific community is still developing methodology for detecting and aging bruises with more objective methods, but visual detection and the color cycle of a bruise (red, purple, blue, green, and yellow) are generally accepted.

Identifying quality control points for bruising in the livestock supply chain is an ongoing process. By examining each step in the process, the scientific community can evaluate risk factors for bruising and develop methods to equip the livestock industry with relevant information that facility personnel can readily apply to current animal handling programs. Efforts to decrease bruising is an industry-wide effort to improve animal handling and well-being.

Figure 5.1
Potbelly trailer design used to transport cattle with two deck levels.

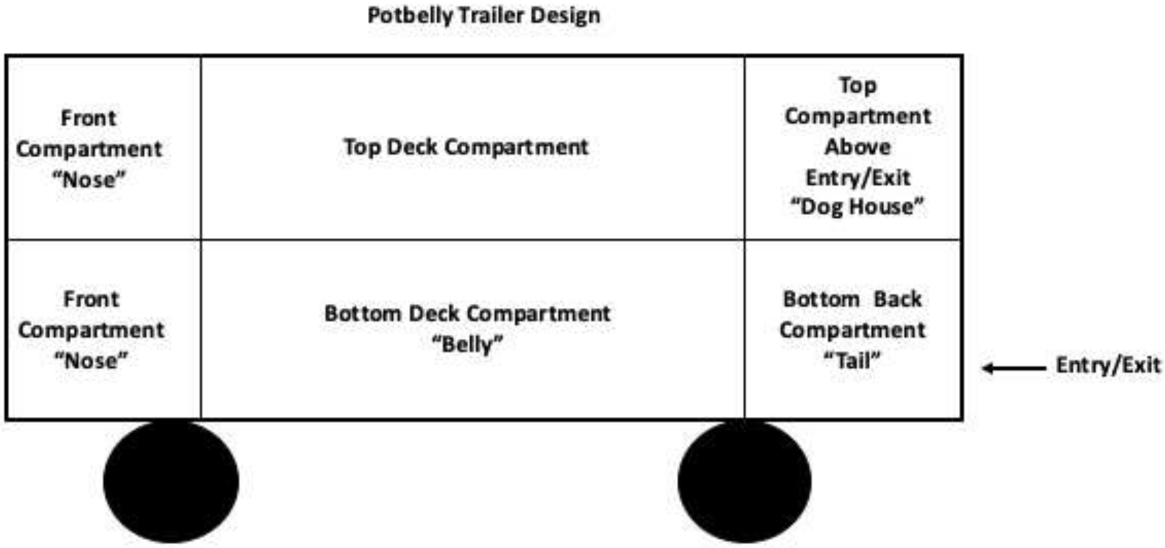


Figure 5.2
Straight trailer design used to transport cattle with a single deck level.

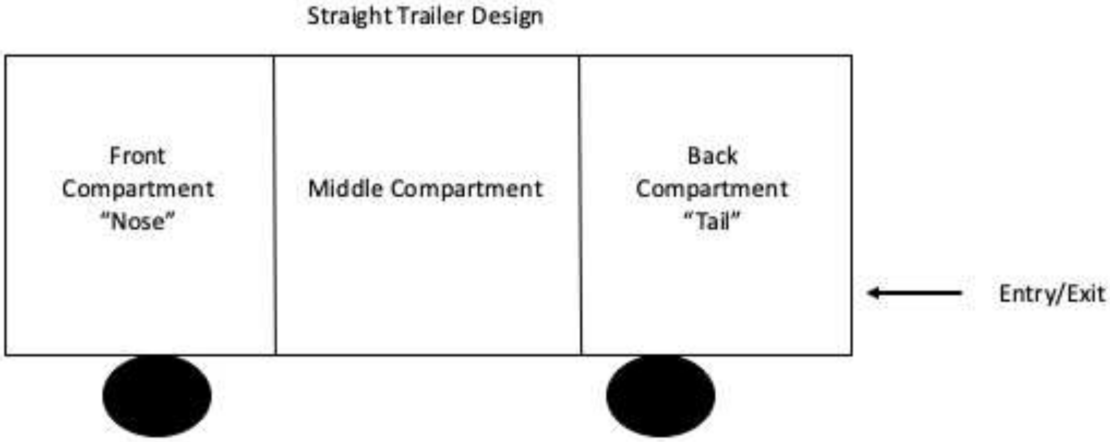
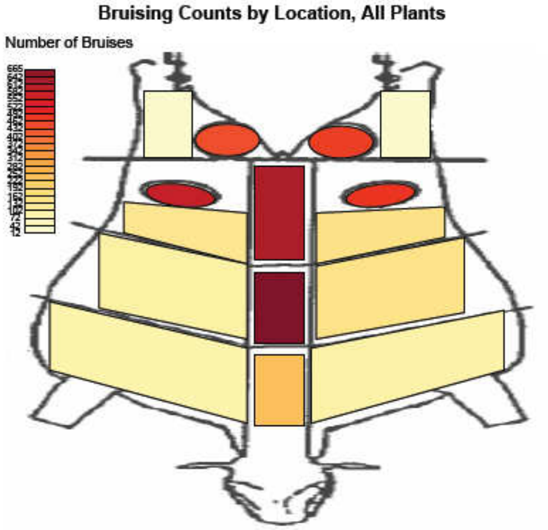


Figure 5.3
Curly Q pattern sprayed onto cattle.

Figure 5.4
Food grade dyes and spray containers.

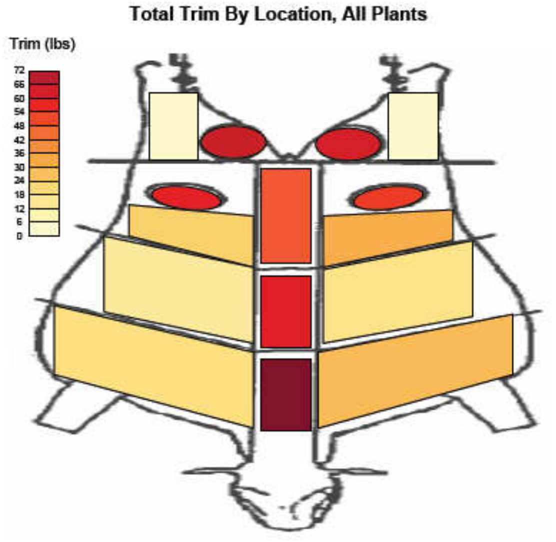
Figure 5.5
Estrotect colored patches used on solid color hided cattle.

Figure 5.6. Bruise counts by location from all facilities.



The darker the color in the figure the higher the bruising incidence for that carcass region.

Figure 5.7. Total bruise trim by carcass location for all facilities.



The darker the color in the figure the heavier bruise trim incidence for that carcass region.

Table 5.1. Carcass cooler assessment data collected (presence or absence was recorded by circling either yes or no for each attribute).

Plant Identification	Down Grade	Loin Damage	Round Damage	Water Pockets	Window Bruise	Abscess	Arthritis
Plant 1	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No
Plant 2	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No
Plant 3	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No
Plant 4	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No
Plant 5	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No
Total	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No

Table 5.2 Bruise video analysis data collection chart completed for each unloading trailer of pre-selected animals.

Date		Plant Identification	Plant Identification	Plant Identification	Plant Identification	Plant Identification
	APPT #	Numeric value	Numeric value	Numeric value	Numeric value	Numeric value
	Trailer Arrival #	Numeric time	Numeric time	Numeric time	Numeric time	Numeric time
	Animal #	Numeric value	Numeric value	Numeric value	Numeric value	Numeric value
	Trailer Type	Straight/potbelly	Straight/potbelly	Straight/potbelly	Straight/potbelly	Straight/potbelly
	Compartment Origin	Compartment	Compartment	Compartment	Compartment	Compartment
	Dye/Patch Color	Color	Color	Color	Color	Color
	Hide Pattern	Color of hide	Color of hide	Color of hide	Color of hide	Color of hide
	Beef/Dairy	Beef/dairy	Beef/dairy	Beef/dairy	Beef/dairy	Beef/dairy
	Back Tag #	Numeric value	Numeric value	Numeric value	Numeric value	Numeric value
	Ear Tag #	Numeric value	Numeric value	Numeric value	Numeric value	Numeric value
	Sex	Bull/steer/heifer/cow	Bull/steer/heifer/cow	Bull/steer/heifer/cow	Bull/steer/heifer/cow	Bull/steer/heifer/cow
	Horns	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No
	Trauma	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No
	Impact Location	Body location	Body location	Body location	Body location	Body location
	Two at once	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No
	Scrape	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No
	Cattle Height	Numeric value	Numeric value	Numeric value	Numeric value	Numeric value

Table 5.3. Beef versus dairy (n = 703).

Plant n = 5	Number of beef breed type carcasses	Number of dairy breed type carcasses
Plant 1	5	125
Plant 2	0	149
Plant 3	117	0
Plant 4	4	152
Plant 5	41	152
Total	167	536

[1] Includes pre-selected animals.

Table 5.4. Carcass sex class incidence (n = 703).

Plant n = 5	Number of bull carcasses	Number of cow carcasses	Number of steer/heifer carcasses
Plant 1	0	28	102
Plant 2	0	19	130
Plant 3	14	52	51
Plant 4	0	38	118
Plant 5	1	90	60
Total	15	227	461

[1] Includes pre-selected animals.

Table 5.5. Horn incidence (n = 704).

Plant n = 5	Number of cattle with horns	Total number of animals	Percentage of animals with horns
Plant 1	0	130	0.0%
Plant 2	13	149	8.7%
Plant 3	4	117	3.4%
Plant 4	7	156	4.5%
Plant 5	1	152	0.7%
Total	25	704	3.6%

[1] Includes pre-selected animals.

Table 5.6. Traumatic event incidence at unloading (n = 704).

Plant n = 5	Number of animals with traumatic events at unloading	Total number of animals	Percentage of animals with traumatic events at unloading
Plant 1	4	130	3.0%
Plant 2	9	149	6.0%
Plant 3	6	117	5.1%
Plant 4	4	156	2.6%
Plant 5	2	152	1.3%
Total	25	704	3.6%

[1] Includes pre-selected animals.

Table 5.7. Cattle derived from auction barn versus not derived from auction barn origin (n = 576).

Plant n = 5	Auction barn bruised cattle	Total number of auction barn cattle	Percentage of auction barn bruised animals	Non-auction barn bruised cattle	Total number of non-auction barn cattle	Percentage of non-auction barn bruised animals
Plant 1	20	41	48.8%	10	38	26.3%
Plant 2	14	34	41.2%	38	87	43.7%
Plant 3	58	95	61.1%	10	12	83.3%
Plant 4	8	30	26.7%	29	99	29.3%
Plant 5	31	70	44.3%	26	70	37.1%
Total	131	270	48.5%	113	306	36.9%

[1] Bruised means visibly bruised.

[2] Auction barn 95% CI (42.54, 54.46; n = 270)
Non-auction barn 95% CI (31.92, 41.88; n = 306)

Table 5.8. Body condition score versus bruising incidence (n = 140).

Body Condition Score (BCS)	1	2	3	4	5	6
Percent cattle bruised	58.3% n = 11	56.1% n = 38	44.1% n = 35	25.7% n = 37	11.8% n = 17	100% n = 1

[1] BCS 1 Emaciated with muscle atrophy and no detectable fat. Tail head and ribs project predominantly.
BCS 2 Muscle atrophy and no detectable fat. Tail head and ribs prominent.
BCS 3 Slight muscle atrophy. All ribs visible.
BCS 4 Outline of spine slightly visible, 3 to 5 ribs visible. Some fat over ribs and hips.
BCS 5 Outline of spine not visible, 1-2 ribs visible. Fat over hips but still visible.
BCS 6 Ribs and spine no longer visible with some fat in brisket and flanks

Table 5.9. Driver's experience transporting cattle in commercial hauls (n = 144).

Plant n = 5	Drivers with <2 years experience	Drivers with 2≤x≤ 10 years experience	Drivers with >10 years experience	Std. Dev. (years)	Min (years)	Max (years)
Plant 1	1	6	19	9.40	1.5	40
Plant 2	0	11	20	12.41	3	45
Plant 3	3	8	15	5.63	1	43
Plant 4	11	12	7	7.00	0.019	25
Plant 5	2	18	10	10.25	1	40
Total	17 (11.8%)	55 (38.2%)	71 (49.3%)	11.64	0.019	45

[1] Range of experience: 0.019 years – 45 years

Table 5.10. Distance travelled by cattle in commercial haul (n = 104).

Plant n = 5	Haul distance <161 (km)	Haul distance 161≤x≤ 402 (km)	Haul distance >402 (km)	Std. Dev. (km)	Min (km)	Max (km)
Plant 1	n/a	n/a	n/a	n/a	n/a	n/a
Plant 2	2	15	2	213.77	112.65	1,100.79
Plant 3	0	15	10	319.89	193.12	1,070.21
Plant 4	0	18	12	381.25	177.03	1,367.94
Plant 5	4	3	23	367.62	96.56	1,367.94
Total	6 (5.8%)	51 (49.0%)	47 (45.2%)	359.56	96.56	1,367.94

[1] Range of haul distance: 96.56 km - 1,367.94 km

Table 5.11. Percentage of cattle bruised by trailer type (n = 585).

Plant n = 5	Potbelly trailer bruised cattle	Total number of potbelly trailer cattle	Percentage of potbelly trailer bruised animals	Straight trailer bruised cattle	Total number of straight trailer cattle	Percentage of straight trailer bruised animals
Plant 1	26	69	37.7%	4	10	40.0%
Plant 2	57	130	43.8%	n/a	n/a	n/a
Plant 3	68	107	63.6%	n/a	n/a	n/a
Plant 4	37	129	28.7%	n/a	n/a	n/a
Plant 5	52	132	39.4%	5	8	62.5%
Total	240	567	42.3%	9	18	50.0%

[1] Bruised means visibly bruised.

[2] Includes pre-selected animals.

Table 5.12. Percentage of cattle bruising by trailer compartment (n = 585).

Trailer compartment	Total bruised cattle	Total number cattle	
Belly	89	190	46.8%
Dog house	5	9	55.6%
Tail	52	107	48.6%
Nose	34	76	44.7%
Top deck	63	190	33.2%
Front, straight trailer	4	7	57.1%
Middle, straight trailer	2	6	33.3%

[1] Bruised means visibly bruised.

[2] Includes pre-selected animals.

[3] 46.8% of the cattle from the belly compartment were bruised (95% CI: 39.7, 53.9; n = 190),
44.7% of the cattle from the nose compartment were bruised (95% CI: 33.52, 55.88; n = 76),
48.6% of the cattle from the tail compartment were bruised (95% CI: 39.13, 58.07; n = 107)
33.2% of the cattle from the top deck compartment were bruised (95% CI: 26.50, 39.90; n = 190)

Table 5.13. Visible carcass bruising and carcass location of bruise (n = 2,532).

Plant n = 5	R1	R2	R3	R4	5A	5B	5C	R6	R7	L1	L2	L3	L4	L6	L7
Plant 1	3	46	17	8	70	218	167	71	95	5	69	46	14	97	219
Plant 2	1	24	22	4	42	182	139	54	75	0	12	16	6	33	58
Plant 3	6	36	34	51	60	89	157	62	193	4	10	12	7	67	102
Plant 4	1	6	8	12	29	130	99	14	29	2	36	52	37	25	91
Plant 5	2	10	5	6	27	46	44	225	76	1	13	8	7	229	97
Total	13	122	86	81	228	665	606	426	468	12	140	134	71	451	567

[1] This table includes carcasses that were visibly bruised.

[2] R1 and L1 (hocks); R2 and L2 (loin); R3 and L3 (rib); R4 and L4 (chuck); 5A (dorsal chuck); 5B (dorsal rib); 5C (dorsal loin); R6 and L6 (round); R7 and L7 (round).

Table 5.14. Overall visible carcass bruising incidence rate (n = 8,962).

Plant n = 5	Visibly bruised carcasses n = 2,519	Total number of carcasses n = 8,962	Percent of visibly bruised carcasses
Plant 1	820	2,484	33.0%
Plant 2	498	1,756	28.4%
Plant 3	491	1,255	39.1%
Plant 4	356	2,120	16.8%
Plant 5	354	1,347	26.3%
Total	2,519	8,962	28.1%

[1] This table includes carcasses that were visibly bruised.

[2] Includes pre-selected carcasses and shift processed carcasses.

Table 5.15. Percentage of cattle bruised when categorized by sex class (n = 585).

Plant n = 5	Bruised bulls	Total bulls	Percentage of bruised bulls	Bruised cows	Total cows	Percentage of bruised cows	Bruised steers/heifers	Total steers/heifers	Percentage of bruised steers/heifers
Plant 1	n/a	n/a	n/a	7	15	46.7%	23	64	35.9%
Plant 2	n/a	n/a	n/a	7	19	36.8%	50	111	45.0%
Plant 3	9	13	69.2%	32	48	66.7%	27	46	58.7%
Plant 4	n/a	n/a	n/a	9	23	39.1%	28	106	26.4%
Plant 5	0	1	0.0%	47	88	53.4%	10	51	19.6%
Total	9	14	64.3%	102	193	52.8%	138	378	36.5%

[1] Bruised means visibly bruised.

[2] Bruised cow 95% CI (45.76, 59.84; n = 193)
bruised steer/heifer 95% CI (31.65, 41.35; n = 378)

Table 5.16. Percentage of cattle bruised when categorized by beef breed type versus dairy breed type cattle (n = 576).

Plant n = 5	Beef breed type bruised cattle	Total number of beef breed type cattle	Percentage of beef breed type bruised animals	Dairy breed type bruised cattle	Total number of dairy breed type cattle	Percentage of dairy breed type bruised animals
Plant 1	n/a	n/a	n/a	30	79	38.0%
Plant 2	n/a	n/a	n/a	57	130	43.8%
Plant 3	68	107	63.6%	n/a	n/a	n/a
Plant 4	5	31	16.1%	52	109	47.7%
Plant 5	0	2	0.0%	37	127	29.1%
Total	73	140	52.1%	176	445	39.6%

[1] Bruised means visibly bruised.

[2] Beef breed type bruised 95% CI (43.82, 60.38; n = 140)
dairy breed type bruised 95% CI (35.06, 44.14; n = 445)

Table 5.17. Percentages of visible bruise color incidence on carcasses (n = 2,532).

Carcass location	1	2	3	4	Carcass location totals
Area R1	6	5	1	0	12
Area R2	20	82	19	1	122
Area R3	10	22	27	0	59
Area R4	10	34	17	0	61
Area 5A	35	119	51	0	205
Area 5B	78	349	121	3	551
Area 5C	59	249	59	0	367
Area R6	24	308	16	0	348
Area R7	17	245	18	0	280
Area L1	5	2	0	0	7
Area L2	11	46	12	0	69
Area L3	6	35	26	0	67
Area L4	9	14	11	0	34
Area L6	11	92	9	0	112
Area L7	20	206	11	1	238
Total	321	1,808	398	5	2,532
Color percentage	12.7%	71.4%	15.7%	0.20%	

[1] 1 (bright red bruise color); 2 (dark red/purple bruise color); 3 (light red/purple/green watery consistency bruise color); 4 (rusty light orange bruise color).

[2] Some carcasses had multiple bruises.

[3] R1 and L1 (hocks); R2 and L2 (loin); R3 and L3 (rib); R4 and L4 (chuck); 5A (dorsal chuck); 5B (dorsal rib); 5C (dorsal loin); R6 and L6 (round); R7 and L7 (round).

Table 5.18. Carcass bruising incidence rate and bruise trim collection incidence rate (n = 617).

	Bruise trim loss collected		
Visible bruising observed	Yes	No	Total
Yes	199.0	61.0	260.0
No	149.0	208.0	357.0
Total	348.0	269.0	617.0

[1] Includes pre-selected carcasses that had a bruise evaluation score and a matching bruise trim value.

Table 5.19. Carcass downgrade incidence in carcass cooler assessment (n = 585).

Plant n = 5	Number of downgraded carcasses	Number of carcasses n = 585	Percent of downgraded carcasses
Plant 1	1	96	1.0%
Plant 2	3	128	2.3%
Plant 3	5	109	4.6%
Plant 4	1	140	0.7%
Plant 5	0	112	0.0%
Total	10	585	1.7%

[1] Includes pre-selected carcasses.

Table 5.20. Carcass window bruise incidence in carcass cooler assessment (n = 585).

Plant n = 5	Number of window bruised carcasses	number of carcasses n = 585	Percent of window bruised carcasses
Plant 1	4	96	4.2%
Plant 2	4	128	3.1%
Plant 3	11	109	10.1%
Plant 4	10	140	7.1%
Plant 5	38	112	33.9%
Total	67	585	11.5%

[1] Includes pre-selected carcasses.

Table 5.21. Carcass average bruise trim weight by observed facility (n = 361).

Plant n = 5	Total bruise trim weight (kg)	Total number of carcasses n = 361	Average bruise trim weight (kg)	Std. Dev.
Plant 1	35.58	25	1.42	1.23
Plant 2	26.19	55	0.48	6.54
Plant 3	118.43	86	1.38	2.24
Plant 4	50.08	84	0.59	1.68
Plant 5	132.04	111	1.19	0.96
Total	362.32	361	1.00	16.59

[1] Includes carcasses that had non-zero bruise trim weights.

Table 5.22. Percentage of bruise trim loss incidence with carcasses categorized by sex class (n = 604).

Animal type	Carcasses with bruise trim loss	Number of carcasses n = 604	Bruise trim loss incidence
Bull	10	13	76.9%
Cow	132	181	72.9%
Steer/Heifer	204	410	49.8%

[1] Includes pre-selected animals.

Table 5.23. Visible carcass bruising and associated bruise trim weight with carcass bruise location (kg) (n = 2,532).

Plant n = 5	R1	R2	R3	R4	5A	5B	5C	R6	R7	L1	L2	L3	L4	L6	L7
Plant 1	0	0	1.43	0	1.56	3.71	2.63	0.13	0.06	0	1.99	1.81	0	0.15	2.10
Plant 2	0	1.83	0.78	1.67	1.37	4.61	2.73	0.39	1.08	0	0	0	0.37	0.13	4.81
Plant 3	0	4.52	2.54	6.51	7.39	10.98	12.31	3.19	8.25	0	7.55	0.68	1.04	3.84	9.27
Plant 4	0.18	2.48	0	1.0	4.90	5.66	1.20	6.67	2.84	0.18	1.86	0.16	3.57	0.55	2.60
Plant 5	0.24	0.57	0	1.35	5.44	1.16	0.94	50.49	8.70	0	1.54	0.25	1.35	23.57	6.57
Total	0.42	9.40	4.74	10.53	20.66	26.11	19.79	60.88	22.28	0.18	12.94	2.90	6.33	28.24	25.34

[1] This table includes carcasses that were visibly bruised and all cattle sex classes.

[2] R1 and L1 (hocks); R2 and L2 (loin); R3 and L3 (rib); R4 and L4 (chuck); 5A (dorsal chuck); 5B (dorsal rib); 5C (dorsal loin); R6 and L6 (round); R7 and L7 (round).

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Chapter VI

CARCASS BRUISE TRIM WEIGHTS AND VISUAL EVALUATION

SUMMARY: A total of 1,347 *Bos taurus* beef carcasses were observed at one slaughter facility; they had a bruising incidence rate of 26.3%. Of the total carcasses observed, 140 were pre-selected carcasses for evaluation in this study, and 111 generated trimmings from bruising that was collected by the two observers. A total of 68.6% of bruise trimmings collected were assessed correctly using the National Beef Quality Audit Bruise Size Key visual assessment tool. As trimmings weight from bruises increased, the observer underestimated bruise trimmings weights more often than overestimating bruise trimmings weights.

INTRODUCTION

At processing facilities, bruised areas must be trimmed off the carcasses. Marshall (1977) stated that bruised bovine tissue is more likely to harbor potential pathogenic and spoilage organisms than healthy tissue, but the major reason for removing bruises from cattle carcasses was because bruised tissue was not aesthetically pleasing to the consumer. The bruise trimmings do not have value as a product for human consumption; they must therefore be sent to rendering or used to make pet food (Coffeen, 2014). It was calculated that US$11.47 were lost per beef carcass in 1994 (National Cattlemen's Beef Association, 1994) due to bruising. In the National Market Cow and Bull Beef Quality Audit -1999, bruising was the sixth leading cause of whole carcass condemnation (Roeber et al., 2001).

An annual loss of US$14,452,000 was calculated for the fed beef industry due to bruising in 1998

(Boleman et al., 1998), and in 1999 US$2.24 was lost per carcass due to bruising (National Cattlemen's Beef Association, 2017).

The National Beef Quality Audit 2016 (NBQA-2016) for finished cattle documented that 38.8% of fed cattle carcasses were bruised, 64.1% of observed cow carcasses were bruised, and 42.9% of observed bull carcasses were bruised (Eastwood et al., 2017; Harris et al., 2017). Bruises can cause economic loss in the beef industry and can be indicators of animal welfare concerns during pre-slaughter animal handling management (Jarvis et al., 1995).

Hamdy et al. (1957a) stated that, on slaughtered animals, the method most used to assess bruises is 'gross observation and color changes' to assess bruises. The National Beef Quality Audit surveys have utilized visual methods to determine bruise trimming weights for all the audits since inception in 1991 to the most recent audit conducted in 2016. This study was conducted to assess the accuracy of using visually-determining bruising assessment to predict bruise trimmings weights on bovine carcasses on the slaughter floor and expand upon the benchmarking studies of the National Beef Quality Audits.

MATERIALS AND METHODS

Ethical Statement

All animal measurements and observations that occurred at the commercial slaughter facilities were non-invasive and an exemption petition was filed and granted by the Colorado State University Animal Care and Use Committee for this study. This study was a collaborative effort with the slaughter facilities and Colorado State University.

Facility and pre-selected animals

This study was conducted at a commercial cattle slaughter facility that processes culled cows, culled bulls, and fed steers and heifers, in March 2018. The plant was located in northeastern region of the United States. Data were collected over the course of one week at the slaughter facility. The slaughter facility was a single-production shift plant operating one 9 hour shift each day, and slaughtering approximately 1,100 to 1,950 cattle per day at a rate of approximately 140 to 280 head per hour when operating at normal facility capacity. Cattle arrived at the processing facility on research days and were randomly selected as they exited shipment trailers, from each trailer compartment, at the unloading docks for individual animal identification. The cattle in this study were selected individually identified through the slaughtering process as described in Chapter 5. Individual animal identification was maintained throughout the process by multiple locations of tag transfer and carcass identification recording.

Bruise Identification and Trim Weight Assessment and Measurement

Bruise presence was recorded for sampled carcasses and hundreds of other processed carcasses at the slaughter facility. One observer was positioned to evaluate bruises on carcasses before carcass splitting and after the hide puller positions in the slaughter facility.

A modified version of the Strappini et al. (2012a) diagram was used to record bruising incidence for each carcass. The observer assessed visible bruises carcass surface and not deep tissue bruises that were not visible on the surface. After assessing bruise presence, location, and color the observer attached two laminated CSU tags that had been sterilized at a hot water station to either side of the carcass spine using shroud pins. These tags were in addition to the previously placed tags (as described in Chapter 5). Trim from both visible and deep tissue bruises was collected from each of the identified carcasses. Two researchers were positioned at the final trim rail where carcasses were examined a final time by plant personnel.

One observer collected bruise trim with the assistance of a designated facility employee, while the other observer recorded data. Observers collected bruise trimmings from the pre-selected sample carcasses. Observers pre-labeled clear plastic liver bags with individual identification for ease of data collection for each of the three collection days. Observers recorded carcass identification and liver bag identification from each marked sample carcass. Once the bruise trimmings were collected, the liver bag was sealed and placed in a large bucket on wheels for weighing.

One observer visually assessed the bruise trim, from the pre-selected carcasses, utilizing the NBQA Bruise Size Key. In the NBQA Audit bruises are assessed on the carcass but for this study bruises were assessed once removed from the carcass. The NBQA Bruise Size Key defines minimal bruise trimmings as less than 0.45 kg; major bruise trimmings as 0.45 kg to 4.54 kg, critical bruise trimmings as between 5.0 kg to 18.14 kg, and extreme bruise trim as the entire primal being removed (Harris et al., 2017). The NBQA Bruise Size Key also uses a numeric scoring system for ease of data collection in slaughter facilities. In this bruise assessment system, a score of 1 = a quarter size, 2 = a silver dollar size, 3 = a deck of cards, 4 = 0.45 kg to 1.36 kg, 5 = 1.81 kg to 3.18 kg, 6 = 3.63 kg to 4.54 kg, 7 = 4.99 kg to 9.07 kg, 8 = 9.53 kg to 13.61 kg, 9 = 14.06 to 18.14 kg, and 10 = entire primal was trimmed (Harris et al., 2017). NBQA Bruise Size Key was given with a visual reference of the size of a deck of cards and a quarter (Figure 6.1). The observer recorded bag identification and numeric NBQA score for each bag of trim. This observer was not permitted to see the screen on the scale to prevent the observer from training her eyes using a method other than the NBQA Bruise Size Key. The second researcher weighed each bag of bruise trimmings on a designated scale and recorded the actual bruise weight from the scale and bag identification.

Statistical Analysis

Data were analyzed using the software R (R Core Team (2016) with $\alpha = 0.05$. Summary statics, confidence intervals, and tests for correlations between two paired samples to draw inferences from the sample data were performed. Data were analyzed to evaluate differences in bruise trim evaluation methods.

RESULTS AND DISCUSSION

The data were analyzed to assess accuracy of visual bruise trim weight assessment compared to actual weighing of the bruise trim on the scale. Of the total pre-selected carcasses observed (n = 140), 111 of these carcasses experienced bruise trim removal. The percentage of bruise trim collections assessed correctly per NBQA Bruise Size Key category is given in Table 6.1. The observer accurately assessed the weight of the bruise trim visually 68.6% of the time. The observer's accuracy of visually assessing bruise trimmings weight decreased as the weight of bruise trimmings increased (Figure 6.2). As bruise trimmings weight increased, the observer underestimated the weight more often than overestimating the weight.

Grandin (1980) summarized two methods that have been used to calculate the economic impact of bruising in the livestock industry. The first method was the *Carcass Damage Fax* database. This data base was managed by Livestock Conservation Institute and multiple large beef production companies entered carcass bruising information into the data base to see how they compared to one another. Identities remained anonymous, but companies could see how they ranked in bruising compared to one another. This data base no longer is in use by industry.

The second method used to calculate the economic impact of bruising in the livestock industry was the "trim loss method". This method required weighing bruises trimmed off, and then calculating the bruise monetary value based on their location from the carcass. This method is believed to be the more precise and accurate method, but it is the more labor intensive (Grandin, 1980).

It has also been acknowledged that any bruised tissue trimmed from a beef carcass reduces value and yield from possible downgrading of the carcass (Warriss, 1990; McNally and Warriss, 1996). The method of visual assessment on the slaughter floor to assess the weight of an amount of bruise trim is difficult on the observer and requires consistent visual training. Visual assessment has long been the most practical and easiest method for bruise identification (Trujillo et al., 1996). The National Beef Quality Audit has utilized visual methods to determine bruise trim weights from 1991-2016. Due to the complexity and large-scale design of the National Beef Quality Audit the visual bruise assessment method is the most practical method to assess bruises the industry currently has. However, weighing of the bruise trim would provide a more objective measurement but would be more labor intensive.

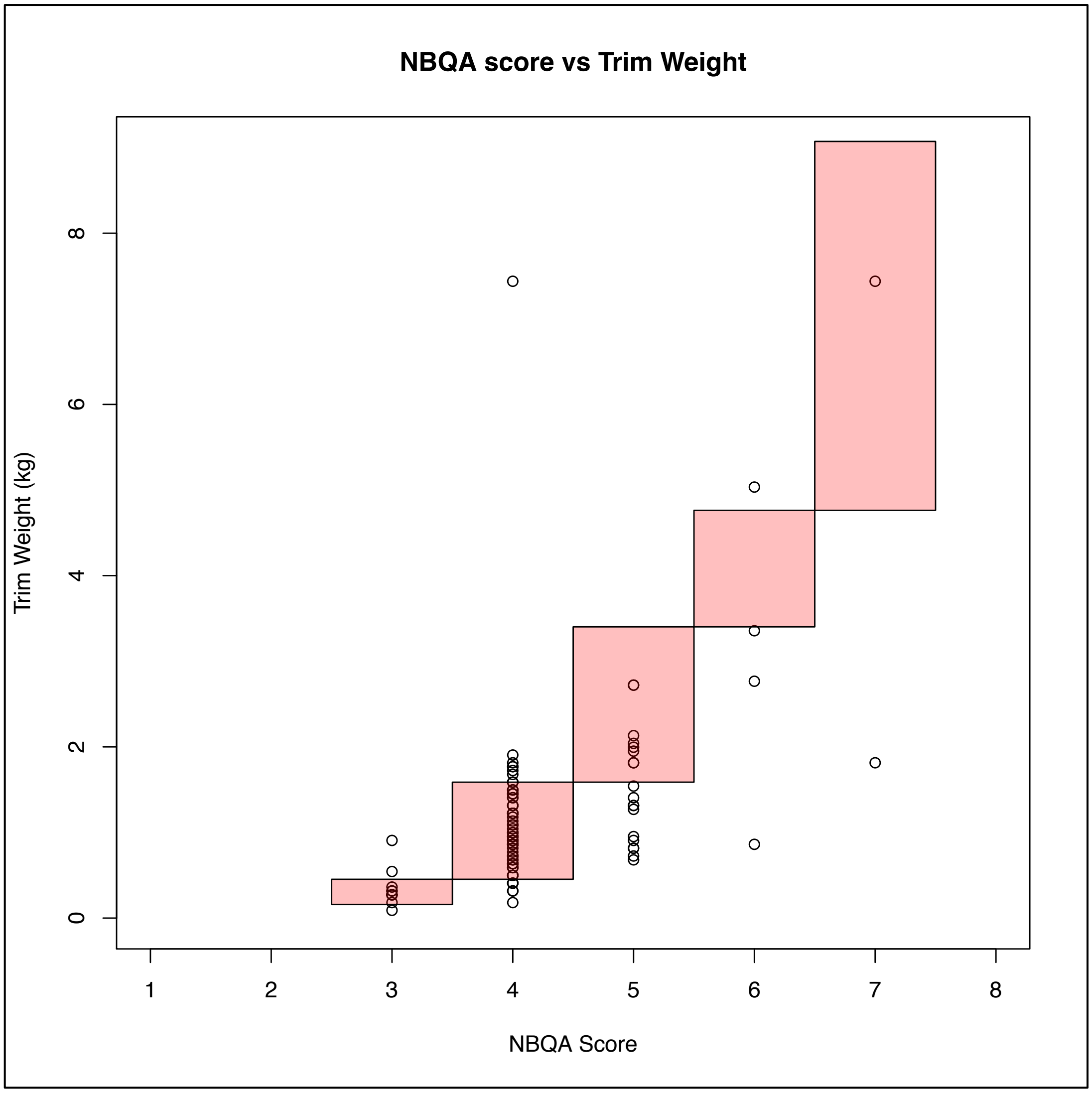
Creating a video training tool that demonstrates the trimming of carcasses and the different trimmings weight categories by creating piles of trim would allow observers to recalibrate as often as needed. This tool would also allow the observer to see different bruise trimmings amounts that fit into the NBQA Bruise Size Key bruise weight categories. By assessing bruises on the carcass, the observer is unable to determine the depth of the bruise. By trimming off the bruises the severity of the bruise tissue can be accurately assessed. If this study had assessed bruises on the carcasses the bruise severity categories may have not been accurately reflected.

Identifying the most practical and objective method to assess impact of bruising on the livestock industry allows the industry to make decisions with the most current and reliable information. As the livestock industry continues to progress toward new methods of bruise trimmings assessment, it may become possible to quantify the economic impact of bruising in the livestock industry with more precision.

Figure 6.1
Visual National Beef Quality Audit (NBQA) Bruise Size Key references

Visual references used within the NBQA Bruise Size Key.

Figure 6.2
Visual appraisal of bruise trim by trained observer using the National Beef Quality Audit Bruise Size Key and the actual weight of bruise trim



Data points represent bruise trim weights and red boxes represent NBQA Bruise Size Key bruise trim weight ranges. Points that lie within the box were visually categorized correctly using the NBQA Bruise Size Key.

[1]No bruises were assessed for bruise severity category 1,2,8,9,10.

[2] Category3 = a deck of cards, category 4 = 0.45 kg to 1.36 kg, category 5 = 1.81 kg to 3.18 kg, category 6 = 3.63 kg to 4.54 kg, category 7 = 4.99 kg to 9.07 kg

Table 6.1 National Beef Quality Audit (NBQA) Bruise Size Key score, actual bruise trim weight and percentage of trim collections assessed correctly (n = 111).

NBQA bruise severity category	NBQA bruise trim weight ranges (kg)	Number of bruise trim collections assessed correctly	Number of bruise trim collections	Percentage of trim collections
3	0.15 – 0.22	7	11	63.6%
4	0.45 - 1.36	56	69	81.2%
5	1.81 – 3.12	8	19	42.1%
6	3.63 - 4.54	0	4	0.0%
7	5.0 – 9.07	1	2	50.0%
Total	--	72	105	68.6%

[1] Carcasses with zero trim not included in table

[2] 63.6% of category 3 were assessed correctly (95% CI: 35.63, 92.37; n = 11)
81.2% of category 4 were assessed correctly (95% CI: 71.74, 90.26; n = 69
42.1% of category 5 were assessed correctly (95% CI: 19.81, 64.19; n = 19)

[3] No bruises were assessed for bruise severity category 1,2,8,9,10

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