Analysis of the use of the "CASH" Dispatch Kit captive bolt gun as a single stage euthanasia process for pigs

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Analysis of the use of the “CASH” Dispatch Kit captive bolt gun as a single stage euthanasia process for pigs

by

Jennifer Anne Woods

A thesis submitted to the graduate faculty in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Veterinary Preventative Medicine

Program of Study Committee:
Suzanne Millman, Major Professor
Anna Butters-Johnson
Annette O’Connor

Iowa State University
Ames, Iowa
2012

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CHAPTER 1. GENERAL INTRODUCTION

Introduction

Euthanasia is a necessary part of production animal management of which the process by which an animal dies is critical to their welfare (Yeates, 2010). In the swine industry, pigs may require euthanasia due to injury, illness, disease, poor production or economics. Euthanasia of swine is a production practice that has seen very little research resulting in limited available literature for producers (Irwin, 2010). This deficiency has highlighted the need for further research to improve animal welfare during euthanasia.

Thesis Organization

Chapter 1 of this thesis will provide a general literature review of relevant research pertaining to the euthanasia of swine and the use of captive bolt guns. A comparison of other acceptable methods of mechanical euthanasia, traumatic brain injury and means of determining death will also be reviewed. A summary and the stated objectives of this thesis will conclude this chapter.

Chapter 2 will provide the results of the laboratory trials where anesthetized pigs were euthanized with the "CASH" Dispatch Kit and the resulting traumatic brain injury scoring.

Chapter 3 reports the outcome of use of the "CASH" Dispatch Kit on farm among numerous stockpersons.

This thesis concludes with general conclusions and recommendations for further research in Chapter 4.
Literature Review

Definition of euthanasia

Euthanasia is derived from the Greek words “eu” and “thanatos” which translates as “good death”. The killing of an animal meets this definition when death is achieved with a minimal amount of pain, fear and distress to the animal (AVMA, 2007). Like companion animals, the use of the term euthanasia to describe the humane killing of animals is limited to the past few decades. Before then, the process was often referred to as “put down”, “putting to sleep”, “sacrificed” or “destroyed” (Zweighaft, 1990).

The swine industry has struggled with ensuring proper euthanasia for many years. As swine husbandry practices have become an ever-increasing concern of the consuming public and a target for animal rights organizations, the pressure to develop effective euthanasia tools and training material for producers has increased significantly. The American Association of Swine Veterinarians (AASV) and the National Pork Board (NPB) recognized this need and in collaboration, produced the first “Euthanasia Handbook” in 1999. For the past several years the NPB has also prioritized the need for research related to euthanasia in their call for requests for proposals in the area of animal welfare.

Traumatic Brain Injury and Concussion

Mechanical euthanasia methods are reliant on impact to the skull with a solid object which will disrupt brain function through (1) laceration or crushing of brain tissue, (2) shock waves producing axonal injury, and (3) temporary cavitation (EU Scientific Veterinary Committee, 1997). The desired outcome is the death of the brainstem, which is the central control for respiration. Through cessation of respiration, the heartbeat with
cease, stopping the flow of blood and oxygen to the brain, which results in the death of the brain and the animal. There are 4 specific areas of the brain that control respiration, 2 are in the medulla and regulate inspiration, the basic rhythm of breathing and expiration. The other 2 are located in the pons and they regulate inspiratory volume, respiratory rate and stimulate of the medulla (Reece, 2004).

Concussion is the result of percussion, which is the striking of one solid object with or against another with some degree of force (OED, 2008). Concussions are a jarring injury of the brain resulting in disturbance of cerebral function (Meriam-Webster Medical Dictionary, 2011). Captive bolt guns are an example of percussive devices that provide the force or energy that results in concussion (HSA, 2006). When fired, captive bolt guns cause extremely rapid propagation of a shockwave of kinetic energy through the brain, producing immediate insensibility due to cerebral concussion, which results from abrupt acceleration and deceleration of the brain with the bony casing of the cranium (Adams and Sheridan, 2008). Postmortem examinations have shown that head injuries are likely to be instantly fatal when haemorrhage occurs in the brain stem (Gregory, 2004).

Captive Bolt Guns

Traditionally, captive bolt guns have been used for the stunning of animals at slaughter. Until 2007, manufacturers of captive bolt guns designed and marketed the guns specifically to meat processing plants for stunning at slaughter. For years though, the captive bolt gun has been utilized by swine producers throughout North America for on-farm euthanasia. Because of its original development and marketing as a “stunning” device, the captive bolt gun is primarily recognized only as a stunning device when used for on-farm euthanasia and a secondary method is recommended to ensure death.
Stunning of slaughter animals has taken place since early in the 11th century. The first requirement for stunning, dating to 1336, required that all animals should be “struck” before bleeding (Lambooy and Spanjaard, 1981). This was based upon a simple concussive blow to the head. However, due to concern for injury from animal convulsions, this technique was quickly replaced by driving a spike into the brain. Once firearms became reliable and commonplace, they became the primary method of stunning of livestock for slaughter. However, firearms ran the risk of contaminating the meat product and had an inherent danger to workers. These 2 technologies were combined to produce the early captive bolt guns. With only minor modifications from the original designs, captive bolt guns are still used throughout the world for stunning livestock for slaughter (Lambooy and Spanjaard, 1981).

There are 2 types of captive bolt gun technologies, the penetrating captive bolt and the non-penetrating captive bolt. Traditional penetrating captive bolt guns utilize either compressed air or an explosive charge to propel a concave sharpened metal rod through the skull and into the brain. The penetrative percussive effect is designed to produce a state of immediate unconsciousness, which persists until the animal is rendered permanently insensible (Finnie, 1993).

Non-penetrating captive bolt technology is based upon the 1336 requirement to “strike” the animal before bleeding and is used extensively in the slaughter of cattle, sheep, rabbit and poultry (Lambooy and Spanjaard, 1981). The non-penetrating captive bolt gun also utilizes compressed air or an explosive charge to propel a flat or mushroom-shaped bolt onto the forehead of the animal creating a state of immediate unconsciousness (AASV, 2009).
Traditional penetrating and non-penetrating captive bolts were designed with the intent to “stun” an animal during the slaughtering process (Temple Grandin, Colorado State University, Boulder, CO, USA, personal communication). Most regulations require that a secondary kill step (bleeding or pithing) be applied immediately following stunning to ensure death (HSA, 2006; EFSA, 2004; OIE, 2007). The Canadian Council on Animal Care (CCAC, 1997) clarifies this position by stating that “if the bolt goes through the brain, it should kill the animal, if not it may just stun the animal”. AVMA (2007) allows for the penetrating captive bolt as a single step method of euthanasia for mature swine, in contradiction to other international standards (HSA, 2006; EFSA, 2004; OIE 2007).

International regulatory bodies recognize the non-penetrating captive bolt gun as a form of controlled blunt force trauma in limited applications. It has been suggested that non-penetrating technology should be utilized to replace manual blunt force trauma for euthanasia of neonate piglets, as a non penetrating captive bolt gun repeatedly produces a constant force blow to the head minimizing the high level of variation in technique and application found between operators conducting traditional blunt force (Hill and Woods, 2009).

Penetrating captive bolt guns come in 9 mm, .22 caliber and .25 caliber. Styles include in-line (cylindrical) and pistol grip (resemble a handgun) and consist of a steel bolt, with a flange and piston at one end, housed in a barrel. The bolt is retained within the barrel by a series of cushions that absorb the excess energy of the bolt and keep it within the barrel. The bolt is retracted back into the gun either automatically or manually depending upon the design of the penetrating captive bolt gun (Woods et al., 2010).
Gunpowder propelled penetrating captive bolt guns are dependent on the expansion of gases to propel the piston forward and force the bolt out through the muzzle of the barrel, whereas pneumatic penetrating captive bolt guns are reliant on compressed air. Accurate placement and energy of bolt (bolt velocity) determines effectiveness. Reliability and bolt velocity is dependent on maintenance (in particular, cleaning) and storage of the cartridge charges (Grandin, 1998; AMI, 2010).

Non-penetrating captive bolt guns are available with 2 basic head designs – a blunt, round flat head or a mushroom-shaped bolt. Non-penetrating captive bolt guns induce euthanasia by physical disruption of the brain as the impact of the bolt results in tissue deforming collisions of the cortex to the skull and sudden rotational forces that lead to shearing strains and stresses within the brain.

The physical response to effective captive bolt application is the collapse of the animal, immediate onset of tonic-clonic seizures, loss of corneal reflexes and apnoea (van der Wal et al., 1971). The penetrating captive bolt gun physically disrupts the brain through direct trauma to the brain in 2 stages - penetration of the bolt into the brain and direct injury to the cerebral cortex or brain stem due to concussion. Concussion is created from the impact of the bolt on the skull and results in a shockwave that is sent through the brain leading to instantaneous concussion-induced unconsciousness. Concussion causes functional damage and may thus be reversible (EFSA, 2004). Penetration of the bolt leads to physical damage to the brain, causing irreversible loss of consciousness provided the appropriate areas are destroyed.

Previous research involving the use of the penetrating captive bolt gun on sheep found there were 3 levels of brain damage caused by the application of a captive bolt gun (Daly and Whittington, 1989). First, there was tissue damage in the brain from the
passage of the bolt through the tissue. Second, the high-speed penetration of the bolt within the cranium creates pressure waves within the fluid medium of the brain creating additional damage at sites distant from the bolt trajectory. Lastly, the impact of the bolt on the cranium contributes to the concussion (Daly and Whittington, 1989).

Historically, both the penetrating and the non-penetrating captive bolt gun have had limitations within the euthanasia application. As discussed earlier, the captive bolt gun previously had only been designed for and recognized as a stunning device with very limited endorsement as a single step euthanasia tool. The requirement of a secondary step to ensure death has made the method impractical for many.

Previous research on the effectiveness of the penetrating captive bolt gun on cattle, sheep and water buffalo found it was not reliable as a single step euthanasia method (Daly et al., 1986; Daly et al., 1987; Finnie, 1993; Gregory et al., 2007; Gregory et al., 2009). A more recent study involving 489 sheep, found it was effective as a single step method when the shot was assessed as properly targeted based on trajectory of the bolt (Gibson et al., 2012).

There has been some limited research pertaining to the use of the non-penetrating captive bolt gun on piglets. The application of a traditional mushroom shape non-penetrating gun on 6 to 8 week old pigs found the gun was not effective on this weight class of pigs at all (Finnie, 2003). More recent research related to the development of a pneumatic non-penetrating captive bolt gun for the euthanasia of non-viable piglets on farm found that it was not as reliable for single step euthanasia as traditional manual blunt force trauma (Widowski, 2008). Through modifications to the head of the bolt to a more conical shape, the gun was found to be consistent in rendering the piglet insensible
followed by death (Casey-Trott et al., 2010).

Another limitation is that the captive bolt gun must be held flush to an animal’s head. This can be quite difficult without access to proper restraint. If the gun is not held flush to the animal’s head, the application can be ineffective due to loss of concussion force and depth of penetration (EFSA, 2004).

The skull of the pig itself can create challenges for the use of the captive bolt gun on swine, more so than other species. Mature swine have very large, thick skulls with an expansive sinus cavity situated right in front of their brain (HSA, 2006). This can provide a buffer for the brain from both the penetration of the bolt and the concussion, limiting the gun’s effectiveness. The target area is also very small and can be exacerbated in pigs with dish shape skulls, especially sows (EFSA, 2004).

“CASH” Dispatch Kit

In 2007, the NPB organized a meeting of equipment manufacturers, producers, animal welfare specialists, veterinarians and safety experts to discuss the development of a euthanasia system specifically designed for commercial pork production facilities. These discussions led British manufacturer Accles and Schevolke (Sutton Coldfield, West Midlands, UK) and their North American distributor Bunzl Processor Division (St. Louis, Missouri, USA) to embark upon developing a system specifically designed for the single step euthanasia of swine in commercial operations.

The “CASH” Dispatch Kit is a heavy duty, .25 caliber cartridge propelled captive bolt device with interchangeable muzzle assemblies. The unit provides four head styles: a non-penetrating head which is flat and round, short-length penetrating bolt, medium-length penetrating bolt and extended-length penetrating bolt. (Table 1.1) There are 5
different power cartridges that are coordinated to muzzle type and weight class of the pig. The tips of each cartridge is colored for easy reference. (Table 1.2)

**Euthanasia Considerations**

The achievement of minimal pain, fear and distress during euthanasia requires the use of techniques that induce an immediate loss of consciousness followed by or in conjunction with cardiac and respiratory arrest that ultimately results in loss of brain function. There is a multitude of considerations for evaluating the effectiveness and acceptability of on-farm euthanasia techniques. In the past several years, industry organizations, animal welfare groups and governmental agencies have detailed their primary concerns and recommendations in various publications (EFSA, 2004; FAWC, 2004; AASV, 2009; CCAC, 2007). The *Report of the AVMA Panel on Euthanasia (2007)* is the leading reference for the euthanasia of livestock in North America. In evaluating methods of euthanasia, the AVMA (2007) euthanasia panel utilized the following criteria: (1) ability to induce loss of consciousness and death without causing pain, distress, anxiety or apprehension; (2) time required to induce loss of consciousness; (3) reliability; (4) safety of personnel; (5) irreversibility; (6) compatibility with requirement and purpose; (7) emotional effect on observers or operators; (8) compatibility with subsequent evaluation, examination or use of tissue; (9) drug availability and human abuse potential; (10) compatibility with species, age and health status; (11) ability to maintain equipment in proper working order; and (12) safety for predators/scavengers should the carcass be consumed.

The ability to induce loss of consciousness and death with minimal pain or distress is the most critical of the criteria for animal welfare. The method must render the animal
rapidly unconscious followed by death. Loss of consciousness ensures that the animal is feeling no pain or distress following the application of the euthanasia method and ideally the animal will remain unconsciousness until the death process is complete. Failure to achieve immediate loss of consciousness or return to consciousness is an indicator of poor animal welfare and would not achieve the definition of euthanasia.

The method must be reliable and non-reversible. Ideally, it would consistently deliver effective euthanasia with a single step. According to the American Meat Institutes (AMI) Recommended Animal Handling Guidelines and Audit Guide: A Systematic Approach to Animal Welfare (2010), insensibility on the first attempt with a captive bolt gun must be achieved 95% of the time in order to obtain a passing score on the animal welfare audit. The EFSA (2004) notes, “Killing methods which induces unconsciousness and death either simultaneously or sequentially, and do not rely on bleeding to cause death should be preferred when available and proven to be effective.”

Repeatability of the method is necessary to ensure humaneness. It must consistently euthanize animals while the effectiveness of the method must be repeatable between stockpersons.

Finally, the aesthetics of the procedure must be considered. Though aesthetics are not relevant to the humaneness of the method, it can have an effect on an employee’s willingness to perform the procedure (Matthis, 2004). Poor aesthetics can also make bystanders and the general public uncomfortable with the procedure. Manual blunt force trauma is an example of a humane method of euthanasia when applied correctly, yet it is one that employees are often uncomfortable applying (Matthis, 2004) and that the general public finds very offensive.
Meeting all of these criteria is quite difficult and has limited the number of methods available to producers for on-farm euthanasia.

**Regulations**

There is limited regulation pertaining to the euthanasia of livestock in North America. Although there is debate on whether the killing of animals for food is equivalent to euthanasia, humane slaughter methods do meet the definition of euthanasia (Grandin, 1994). In North America, the most well known guidelines pertaining to the euthanasia of swine are the AVMA (2007) and AASV (2009). Although neither of these documents is regulatory, they are often referenced as industry standards and have been recognized in courts of law, such as the case of Wayne County, Ohio versus Wiles and Stroud (June, 2007).

**Current acceptable methods of euthanasia**

There are 3 mechanisms for the induction of death: direct depression of the central nervous system, hypoxia and physical disruption of brain activity (AVMA, 2007). Direct depression of the central nervous system is achieved through the injection of an overdose of barbiturates. Hypoxia, or lack of oxygen, is achieved by exposing animals to high concentrations of gas or through rapid blood loss (exsanguination). Physical disruption of brain activity induces death by physical damage to central nervous system, which results in a disruption of brain activity. Death then occurs as a result of respiratory and cardiac failure (AVMA, 2007).

The AVMA (2007) and AASV (2009) currently recognize the following methods as acceptable means for euthanasia of swine: inhalant anesthetics (i.e. carbon dioxide), barbiturate overdose, penetrating captive bolt gun, blow to the head, gunshot and
electrocution. Each one of these methods have advantages and disadvantages. Captive bolt gun, blow to the head and gunshot are the most widely used mechanical methods of euthanasia.

Gunshot is a common method of euthanasia that kills through physical disruption of brain activity. The degree of brain damage inflicted by the bullet is dependent upon the firearm, nature of the bullet (or shot shell) and accuracy of the shot. It is very effective when the proper firearm is used and the placement of the shot is accurate (AVMA, 2007; AASV, 2009). Gunshot can be dangerous to the stockperson, bystanders and other animals due to the chance of ricochet (AASV, 2009).

There are 2 classifications of blunt force trauma – manual and controlled. Manual blunt force trauma was found to be reliable in rendering day old piglets immediately insensible without a return to consciousness (Widowski, 2008). A single, sharp blow must be delivered to the central skull bones with sufficient force to produce immediate depression of the central nervous system and destruction of brain tissue, without breaking open the skull. Manual blunt force trauma is not consistently repeatable and is highly dependent on the skill and comfort with the method of the stockperson. Blunt force trauma, both manual and controlled, also has issues with aesthetics many people find offensive which ties into comfort with the method.

Though manual blunt force trauma is currently approved for neonates by AASV (2009), it is increasingly becoming less acceptable in North America and is not a currently recognized practice for euthanasia of livestock by some international bodies (OIE, 2007). Currently, acceptable tools for controlled blunt force trauma include cartridge and pneumatic non-penetrating captive bolt guns.
Scoring TBI

Though traumatic brain injury (TBI) is referenced in several papers pertaining to physical euthanasia of livestock (Finnie, 1993; Finnie et al., 2003; Gregory et al., 2009), actual scoring systems for TBI has had very limited application in euthanasia research. At the commission of this project, to the author’s knowledge the only available reference to a scoring system for livestock was one used to assess the TBI of horses euthanized using free bullets (Millar and Mills, 2000). Since that time Widowski (2008) published a paper, in which a 5-point scale was utilized to score subcutaneous haemorrhaging, skull fracture and subdural haemorrhaging due to pneumatic non penetrating captive bolt. Gregory et al. (2009) also utilized a 3-point injury rating to describe damage to specific regions of brain following the use of a penetrating captive bolt gun on water buffalo.

Determination of Death

Death is defined by FAWC (2004) as “the cessation of the vital functions of an animal.” The EFSA (1997) has a much more detailed definition: “a physiological state of an animal, where respiration and blood circulation have ceased as the respiratory and circulatory centers in the medulla oblongata are irreversibly inactive. Due to the permanent absence of nutrients and oxygen in the brain, consciousness is irreversibly lost. In the context of the application of stunning and stun/kill methods, the main clinical signs seen are absence of respiration (and no gagging), absence of pulse and absence of corneal and palpebral reflexes and presence of papillary dilation.”

Death is a process that does not occur immediately. Animals are rendered insensible and the body begins to die as the brain stops, respiration ceases, the heart stops beating and the blood quits circulating. This process can take several minutes to occur. “The
process of dying involves points of no return, which can be identified. The irreversible cessation of circulation is a point of no return because it causes critical centers of the brain stem to die. Death of the brain and brainstem is inevitable when intracranial blood pressure exceeds arterial pressure and the brain is deprived of its source of oxygen and glucose. The brainstem also contains centers that initiate and control respiration. When cells in these centers cease to function and die, respiration ceases and life of the whole animal terminates” (Adams and Sheridan, 2008). The heart will continue to function after respiration ceases until the stock of oxygen in the blood is consumed. Once the heart stops rhythmic beating, the brain will no longer receive energy supplies and will also cease to function.

Ideally, death is confirmed through electroencephalogram (EEG), but this method is not practical in the field. The cessation of rhythmic breathing and the onset of respiratory paralysis (apnoea) are the most definitive signs of brainstem death. In the field, death can be determined by cessation of respiration, absence of papillary light reflex, the corneal reflex, cessation of heartbeat and the gag reflex (Gregory, 1998; EFSA, 2004).

**Conclusions and thesis objectives**

Effective methods for the euthanasia of swine on farm are areas that require further investigation. This deficiency in research and published literature may result in a lack of consistency in the application of euthanasia, resulting in poor animal welfare practices and limited resources for producers. Though various methods of physical euthanasia have been utilized on farms for generations, very little research has been performed to determine what is required to make a tool such as a captive bolt gun effective as a single stage method, including the level of TBI required to ensure death is imminent. The
overall objective of this thesis is to evaluate the effectiveness of the single stage captive bolt euthanasia method, the “CASH” Dispatch Kit on all weight classes of pigs.

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Yeates, J.W. 2010. Death is a welfare issue. Journal of Agricultural Environmental

Table 1.1. “CASH” Dispatch bolt types and stem diameters and lengths (Accles and Schevolke, Sutton Coldfield, West Midlands, UK).

<table>
<thead>
<tr>
<th>Muzzle type</th>
<th>Bolt Diameter (cm)</th>
<th>Stem Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Penetrating</td>
<td>3.8 (^a)</td>
<td>N/A (^b)</td>
</tr>
<tr>
<td>Short Bolt</td>
<td>1.2</td>
<td>12.2</td>
</tr>
<tr>
<td>Medium Bolt</td>
<td>1.2</td>
<td>15.5</td>
</tr>
<tr>
<td>Extended Bolt</td>
<td>1.2</td>
<td>17.4</td>
</tr>
</tbody>
</table>

\(^a\) 1.9 cm radius, 1151.1 cm\(^2\) area.

\(^b\) The non-penetrating head does not have a stem that extends from the muzzle and penetrates the skull.
Table 1.2. Recommended muzzle type and powerload for weight classes of pig.

<table>
<thead>
<tr>
<th>Pig Weight Class</th>
<th>Muzzle Type</th>
<th>Powerload&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Nominal Propellant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neonates &amp; Sucklings (&lt;7 kg)</td>
<td>Non penetrating</td>
<td>Pink</td>
<td>135 mg</td>
</tr>
<tr>
<td>Nursery Pigs (7 – 18 kg)</td>
<td>Short Bolt</td>
<td>Pink</td>
<td>135 mg</td>
</tr>
<tr>
<td>Growers (&gt;= 45 kg)</td>
<td>Short Bolt</td>
<td>Yellow</td>
<td>160 mg</td>
</tr>
<tr>
<td>Growers (&gt;= 90 kg)</td>
<td>Medium Bolt</td>
<td>Yellow</td>
<td>169 mg</td>
</tr>
<tr>
<td>Finishers (up to 136 kg)</td>
<td>Medium Bolt</td>
<td>Blue</td>
<td>210 mg</td>
</tr>
<tr>
<td>Finishers &amp; Gilts</td>
<td>Medium Bolt</td>
<td>Orange</td>
<td>265 mg</td>
</tr>
<tr>
<td>Sows &amp; Boars</td>
<td>Extended Bolt</td>
<td>Orange</td>
<td>265 mg</td>
</tr>
<tr>
<td>Large Sows &amp; Boars</td>
<td>Extended Bolt</td>
<td>Black</td>
<td>295 mg</td>
</tr>
</tbody>
</table>

<sup>a</sup>The tip of each cartridge is painted with the coordinating color of the nominal propellant charge for easy identification by users. (Accles and Schervolke, Sutton Coldfield, West Midlands, UK)

<sup>b</sup>The minimal force produced by expanding gas that propels the bolt out of the gun upon firing.
CHAPTER 2: ANALYSIS OF THE USE OF THE “CASH” DISPATCH CAPTIVE BOLT GUN AS A SINGLE STAGE EUTHANASIA PROCESS FOR ANESTHETIZED PIGS

A paper to be submitted to the Journal of Animal Science

ABSTRACT

The objective of this study was to analyze the effectiveness of the “CASH” Dispatch Kit as single step euthanasia method for pigs. Effectiveness was analyzed based on reliability as a single step method of euthanasia of anesthetized pigs across 6 weight classes. Forty-two commercial pigs were enrolled based on weight classes, sex and skull shape. The weight classes were 2-3 kg, 7.5-10 kg, 15-20 kg, 30-40 kg, 100-120 kg, 200+ kg. Four styles of captive bolt gun heads were used - a non-penetrating head, a short penetrating bolt, a medium penetrating bolt and an extended penetrating bolt. Each pig was anesthetized, and then euthanized with the “Cash” Dispatch Kit. Death was determined according to cessation of cardiac and respiratory function. Postmortem dissection was used to determine the presence of hemorrhaging and the extent of traumatic brain injury. All 30 pigs in the 5 lightest weight classes were effectively euthanized. Four of the 12 pigs in the heaviest weight class required a secondary method. With proper application and correct selection of bolt length and cartridge size, the “CASH” Dispatch Kit is an effective one step euthanasia method for pigs under 200 kg. However once pigs weigh 200 kg or more a secondary step may be required.
Introduction

Timely euthanasia is a necessary part of production animal management and a critical tool to provide optimum animal welfare. The American Veterinary Medical Association (AVMA, 2007) and the American Association of Swine Veterinarians (AASV, 2009) both recognize the following mechanical euthanasia methods (1) a captive bolt gun (penetrating or non-penetrating), (2) manual blow to the head and (3) gunshot. Both guidelines allow penetrating captive bolt to be completed as a single step, although in contradiction to other international standards (HSA 2006; EFSA, 2004; OIE, 2007). AASV (2009) recognizes the non-penetrating captive bolt gun as a single step method for pigs up to 5.4 kg and with a secondary method for pigs up to 31.6 kg. In 2007, the National Pork Board (NPB) organized a meeting of euthanasia experts to discuss the development of a device specifically designed for single step mechanical euthanasia for all weight classes of pigs. This led to the development of the “CASH” Dispatch Kit.

Mechanical euthanasia methods are reliant on impact to the skull with a solid object which disrupts brain function through (1) laceration or crushing of brain tissue, (2) shock waves producing axonal injury, and (3) temporary cavitation (EU Scientific Veterinary Committee, 1997). Published research on the use of penetrative captive bolt for other species (cattle, sheep and water buffalo) as a single step euthanasia method concluded that it was unreliable (Daly et al., 1986; Daly et al., 1987; Finnie, 1993; Gregory et al., 2007; Gregory et al., 2009). Published swine euthanasia research using a non-penetrating captive bolt gun as a single step method for euthanasia has been extremely limited (Finnie et al., 2003; Widowski, 2008; Irwin, 2010).

The main objective of this study was to analyze the effectiveness of a new captive
bolt gun technology capable of penetrating and non-penetrating bolt delivery for single step euthanasia of all weight classes of pigs. The second objective was to describe the effectiveness of the device for producing traumatic brain injury to specific regions of the brain, relative to weight class, skull shape and sex.

**Materials and Methods**

All procedures were reviewed and approved by Iowa State University, in accordance with the guidelines from the Institutional Animal Care and Use Committee.

**Animals**

Forty-two commercial pigs were transported to the Iowa State University Veterinary Diagnostic Laboratory from 2 farms in Iowa and 3 farms in Missouri. The pig source all came from the same integrated swine production company. Pigs were selected for culling by farm staff, and were enrolled in the study based on researcher requests for weight, sex and skull shape (Table 2.1). The weight classes were established to encompass all stages of production, and within each weight class equal distribution of sexes and variance in skull shape. Following initial analyses of the data and distribution of the weight classes, the top 2 weight classes were merged into one weight class of mature pigs weighing 200+ kg, thus resulting in six weight classes. A dish shape skull was defined as one that was short and broad. A plank face skull was defined as a long narrow skull. (Table 2.2)

**“CASH” Dispatch Kit**

The “CASH” Dispatch Kit (Accles and Schevolke, Sutton Coldfield, West Midlands, UK) was a heavy duty, .25 caliber cartridge propelled captive bolt device with interchangeable muzzle assemblies. The unit provided 4 bolt head styles (Table 2.3) and 5 power cartridges, coordinated to bolt head type and weight class of the pig (Table 2.4).

**Primary and secondary euthanasia procedure**
The pigs arrived at the ISU Veterinary Diagnostic Laboratory over a 2 d period. The heaviest weight class and the 2 lightest weight classes arrived the afternoon before d 1 of the trial. The 3 intermediate weight classes arrived the afternoon before d 2 of the trials. Pigs were unloaded by lab staff and walked into overnight lairage pens. The 2 lightest weight class piglets were transported in boxes and were carried in their boxes to the pens. All pigs were segregated by weight classes and placed into lairage pens until they were euthanized the following day. Water was provided to all animals in water buckets and tubs.

Upon enrollment in the experiment, each pig was ear tagged and the tag number, sex of pig and anesthesia protocol was recorded. Captive bolt gun head style and cartridge color were selected according to the recommendations by the manufacturer for the weight class, and were documented for each animal. Weight classes 1 through 4 were weighed on a diagnostic laboratory scale (Hobart, Model HBR 300, Serial No. CR-1000199). Pigs in weight classes 5 and 6 were not individually weighed since they exceeded the maximum capacity of the scale, and for these pigs average body weights were estimated from previous performance records kept on the home farm site for the genetic cross and age.

Pigs were individually moved out of the lairage pen and into a central handling area by the researchers using a hog sorting board. Pigs weighing 30 kg or greater were restrained with a snare and anesthetized by an ISU veterinarian using a combination of xylazine (VetTek, lot #54016TT, exp 11/11), ketamine (Ketaset, lot #5401C9X, exp. 02/12) and telazol (Fort Dodge Animal Health, lot 13271, exp 06/20/12). The dose was determined by the attending veterinarian based on the manufacturer’s recommendations.
The attending veterinarian assessed the successful induction of anesthesia by lack of pig response to the following sensibility tests: (1) eye blink response (light touching of the cornea with a finger to detect the presence of involuntary blinking), (2) withdrawal response to a pinch on the coronary band of the leg and (3) withdrawal response or movement in response to a pinch on the snout. Once successful induction of anesthesia was confirmed by the veterinarian, pigs were placed in a sternal lying posture when possible. This was not possible with 200 + kg pigs due to their physical weight and size.

For pigs in weight classes 3 to 6 which were euthanized with a penetrating captive bolt, landmarks for bolt placement were drawn on the skull using a black felt tip marker 1 finger width above the eye based on the current industry guidelines (AASV, 2009). For pigs in weight classes 1 and 2, which were euthanized with the non-penetrating bolt, the gun was centered on the piglet’s forehead.

Before each euthanasia, the recommended captive bolt gun head (bolt length) and corresponding power charge were confirmed by a researcher by cross-referencing to the manufacturers recommendations. The captive bolt gun was loaded, placed perpendicular and firmly against the pig’s skull in the proper location and fired. One researcher immediately confirmed insensibility through corneal reflex, snout and toe pinch. Electrocution was applied as a secondary method to 4 mature animals that were not confirmed dead at the pre-determined 10-min ceiling after the shot was fired.

**Confirmation of death and outcome measures**

Outcomes of interest were time from euthanasia attempt to last detectable heartbeat and presence of respiration. Once clonic movements ceased and researchers could safely approach the animal, the presence of a detectable heartbeat was palpated and time to last
heartbeat was determined using a stopwatch. Once the heartbeat could no longer be palpated, a stethoscope was used to confirm cessation of heartbeat. Presence of rhythmic breathing was observed visually and acoustically. Each animal was pronounced dead when both cessation of heartbeat and respiration were confirmed. If death was not confirmed 10-min after the euthanasia attempt (i.e. a heartbeat or respiration was still detectable), electrocution was used to euthanize the animal. A second researcher documented the presence of orally or nasally audible noises including gasps, groans or grunts, and presence of tonic (stiffening of muscles, lack of movement prior to clonic movement) and clonic (repeated muscular spasms) movements.

**Traumatic brain injury and anatomical variables**

Following euthanasia, the animals in the 4 heaviest weight classes (3 to 6) were exsanguinated and the heads removed with a knife posterior to the 1st vertebrae. The heads were rinsed and unnecessary skin, tissue and bone removed, such that the skin was intact around the point of entry. Piglets in the lightest 2 weight classes that were euthanized with the non-penetrating head were left intact, except for incisions made in the skin over the skull cavity to facilitate penetration of the formalin solution throughout the brain. The cadavers were placed in a 10% formalin mix. Since euthanasia was performed over 2 d, weight classes 3, 4 and 5 soaked for 16 d while classes 1, 2 and 6 soaked for 17 d.

Following partial fixation in formalin, traumatic brain injury was assessed. For pigs euthanized with the non-penetrating captive bolt, skin was cut from the top of the skull and bone fractures removed with tweezers to expose the brain. For pigs euthanized with the penetrating captive bolt, skulls were split longitudinally using knives, a band saw or a
combination of both. The location of bolt penetration was based on the anatomical regions of the brain that were affected: frontal, parietal or occipital. The neuroanatomical structures (cerebral cortex, thalamus, cerebellum, pons and medulla) were scored using a 3 point traumatic brain injury scale (modified from Millar and Mills, 2000): grossly normal (0), some abnormalities (1) and grossly abnormal/unrecognizable (2). Evidence of hemorrhage was noted for each location in the top 4 weight classes (3 to 6), which were euthanized with the penetrating captive bolt gun.

**Experimental design and treatments**

The experimental design was a 6*2*3 factorial arrangement of treatments. Treatments were weight class (1 through 6), sex (female and male) and skull shape (dish, plank and unclear). The experimental unit was the individual pig (n = 42).

**Statistical Analysis**

Data was entered into Microsoft Office Excel 2004 (Microsoft, Redmond, Washington, USA) and verified against written data sheets. Statistical analysis was performed using Statistical Analysis Software (SAS, version 9.2; SAS Institute Inc., Cary, NC, USA).

The frequency of the requirement for second euthanasia procedure and explanatory factors such as weight class and sex were calculated. The association between the requirement for second euthanasia procedure (electrocution) with potential explanatory variables sex, weight class and gun style was assessed using a univariate logistic regression. Quasi-separation of the datasets occurred with weight class and gun style, so descriptive data was obtained using the frequency procedure. A $P$-value of $\leq 0.05$ was considered to be significant for the association between the requirement for a second shot
and sex.

Descriptive information about the time to last heartbeat and explanatory factors such as weight class and sex were calculated. Only animals euthanized with a single shot were included in the analyses. Our proposed analyses were as follows:

Associations between time to last heartbeat and treatment effects sex and weight class were first analyzed using the means procedure in SAS (Version 9.2). Following analyses of the means, the association between time to last heartbeat with the treatment effects was assessed using a mixed procedure in SAS (Version 9.2). A $P$-value of $\leq 0.05$ was considered to be significant.

Descriptive data was obtained using the frequency procedure for categorical treatment effects of weight class on skull shape, level of traumatic brain injury and location of penetration. Descriptive data was also obtained for the treatment effect skull shape on location of penetration.

**Results**

*Primary and secondary euthanasia procedure*

A total of 38 pigs, 30 pigs in the five lowest weight classes (2 to 120 kg) and 8 pigs in the heaviest weight class (200+ kg) were effectively euthanized with the “CASH” Dispatch Kit. Four mature pigs (3 boars and 1 sow) in weight class 6 (200+kg) required a second euthanasia step at the 10 min ceiling

*Confirmation of death*

The mean for time to last heartbeat was 236 s with a range of 451 s. There was a difference between the weight classes ($P =0.02$), but not sex ($P=0.59$), for time to last heartbeat (Table 2.5). Five of the 42 pigs exhibited respiratory activity following
application of the captive bolt gun. A total of 24% of the pigs (n = 10) exhibited audible noises. Audible noises were present even when rhythmic respiration was not detectable, accompanying kicking or occurring immediately after application of the captive bolt gun. Of the 10 pigs that exhibited audible noises, 7 exhibited a single audible noise, one pig exhibited 2 vocal sounds and one required electrocution at the 10 min ceiling due to 80 audible noises described as “snores”, which were not accompanied by detectable respiration. Since the outcome “requirement for second step” was rare, only 4 of 42, and all occurred in only the heaviest weight classes, issues of sparse data and quasi separation of data prevented meaningful hypothesis testing; therefore instead it is presented the descriptive data in Table 2.6.

**Traumatic brain injury and anatomical variables**

Of the 4 pigs that required a secondary euthanasia step, all exhibited hemorrhaging in the cerebral cortex, thalamus and the cerebellum regions of the brain. Two of the 4 pigs had no presence of hemorrhaging in the medulla or pons regions (Table 2.7). Two of the 4 pigs had no direct penetration of the brain in any neuroanatomical region, and traumatic brain injury was present only in the cerebral cortex of the 2 remaining pigs (Table 2.8).

For pigs that did not require a secondary method of euthanasia, all had the presence of hemorrhaging in the cerebral cortex, cerebellum, thalamus, pons and medulla.

Of the pigs euthanized with the penetrating captive bolt (n=30), the bolt penetrated the frontal part of the brain in 24 pigs (Table 2.9). Traumatic brain injury to the cerebral cortex was present in 28 of the 30 pigs of the pigs euthanized with the penetrating captive bolt. Only one pig, in weight class 4 (30 to 40 kg) had visible traumatic brain injury in the thalamus, cerebellum, medulla and pons. The remaining pigs in weight class 4 (and all
other weight classes) had no visible traumatic brain injury in any of these regions.

For the 2 lightest weight classes euthanized with the non-penetrating captive bolt, all displayed a “cookie cutter” effect on the skull, where the bone was cut out in the shape of the bolt head and retropulsed into the brain causing significant trauma, but without breaking the skin. All 12 pigs in the lightest weight class had TBI present in all assessed regions of the brain (Table 2.10).

**Discussion**

**Primary and Secondary euthanasia procedure**

For this single step euthanasia method to be effective, it should induce unconsciousness and death either simultaneously or sequentially, and not rely on bleeding to cause death (EFSA, 2004). Based on expected slaughter standards published by the American Meat Institute (AMI, 2010) insensibility must be achieved 95% of the time when using a captive bolt gun in order to obtain a passing score on the animal welfare audit. The "CASH” Dispatch Kit euthanized 100% of the pigs in the 5 lowest weight classes with a single application, validating its use as a single step method based the above standards (EFSA, 2004; AMI, 2010). For the pigs in weight class 6 weighing 200+ kg, 4 required a secondary method at 10 min. This heavy weight class did not achieve the 95% level of acceptability of outlined by AMI (2010) and EFSA (2004), indicating that pigs 200+ kg and above may require a secondary method of euthanasia.

Captive bolt guns have been designed to have a percussive effect producing a state of immediate and permanent unconsciousness (Finnie, 1993). Traditional penetrating and non-penetrating captive bolts were designed with the intent to “stun” an animal during the slaughtering process (T. Grandin, 2011 personal communication). Concussion is the
result of percussion, which is the striking of one solid with or against another with some degree of force (OED, 2008). Captive bolt guns are an example of percussive stunners that provide the force or energy resulting in concussion (HSA, 2006). When fired, captive bolt guns cause extremely rapid propagation of a shockwave of kinetic energy through the brain producing immediate insensibility due to cerebral concussion which results from abrupt acceleration and deceleration of the brain with the bony casing of the cranium (Adams and Sheridan, 2008). Insensibility is a result of lesions to the reticular formation and to the pathway that connect the reticular formation of the cerebral cortex, and direct injury to the cerebral cortex or brain stem (Erasmus et al., 2010). Death from concussion is due to traumatic brain injury caused by concussion.

The physical response to an effective captive bolt stun is the immediate collapse of the animal, onset of tonic-clonic seizures, loss of corneal reflexes and apnoea (van der Wal, 1971). This is achieved by the penetration of the bolt into the brain and sudden rotational forces leading to shearing strains and stresses within the brain due to concussion. Daly and Whittington (1989) used penetrating captive bolt guns on sheep and reported 3 levels of brain damage. First, there was tissue damage in the brain from the passage of the bolt through the tissue. Second, the high-speed penetration of the bolt within the cranium creates pressure waves within the fluid medium of the brain creating additional damage at sites distant from the bolt trajectory. Lastly, the impact of the bolt on the cranium contributed to the concussion.

Several studies have compared the use of a non-penetrating captive bolt gun on the effectiveness of causing insensibility and death as a single euthanization step. Widowski, (2008) reported that a pneumatic non-penetrating captive gun (termed the “Zephyr” non-
penetrating captive bolt) for non-viable piglets on farm was not a reliable single step for euthanasia on piglets < 24 h old when compared to traditional manual blunt force trauma. Through modifications to the bolt head, adjusting the shape to become more conical, the Zephyr was subsequently found to be consistent in rendering piglets up to 9 kg insensible with the endpoint of death (Casey-Trott et al., 2010). However, Finnie et al., (2003) found contradicting results with the application of a traditional mushroom shape head non-penetrating captive gun on 6, 7 and 8 wk old pigs. The authors concluded that this method was not effective on these weight classes of pigs. This contradiction in results may be due to the fact that the pigs in Finnie's trial were older with a more developed skull than the pigs in pneumatic gun trial. The different outcomes may also be related to differences in the style of guns as the pneumatic gun may produce more concussive force than the gun powder charge gun used by Finnie.

There is a combination of possible factors that may have affected the reliability of “CASH” Dispatch Kit on the heavier weight class animals. First, heavier animals are more mature and have more skull mass. Furthermore, boars and large sows develop a ridge down the middle of the skull making penetration very difficult (EFSA, 2004). As swine mature, their sinus cavity continues to grow in front of their brain, setting the brain farther back in the skull, and hence making penetration to the required depth very difficult on some pigs (EFSA, 2004). The thicker skull has been hypothesized to absorb some of the concussive force, restricting the amount of damage due to concussion, although this has still to be determined.

Positioning of the animal during euthanasia may have also affected the trajectory of the bolt. The large animals were extremely difficult, if not impossible at times, to position
in the desired sternal lying posture creating difficulty in accurate placement and angling of the captive bolt gun. Based on the issues with the larger, mature animals, a request was submitted to the manufacturers of the gun for approval to use a heavier charge (black cartridge - nominal propellant charge 295 mg) in combination with the extended bolt for euthanasia of large animals. Casual observations indicate that this revision has improved the effectiveness on the larger weight classes of pigs, though a secondary method may still be required and stockpersons should be prepared for this.

**Confirmation of insensibility and death**

Ten pigs exhibited some vocalization immediately at the time that euthanization was implemented. These vocal sounds did not raise great concern, since they appeared to be involuntary created from the concussive force of the impact of the gun. There was a difference between the 6 weight classes and time to last heartbeat. The mean time to last heartbeat decreased as the weight class of pigs increased. Casey-Trott, et al. (2010) compared time to last heartbeat between 4 weight classes (3 kg, 4.84 kg, 7.15 kg, 8.76 kg) and found no difference. Possible reasons for these differences between trails may be due to the level of traumatic brain injury, the parts of the brain that are damaged or some physiological differences in the maturity level of the pigs. Such factors would need further investigation. Time to last heartbeat does not have any welfare implications as long as the animal remains insensible until complete cessation as they did in this trial. When an animal is insensible, they do not feel pain nor have an awareness of what is occurring around them (AMI, 2010; HSA, 2006). This information can be used to educate people on the death process. When analyzing time to last heartbeat, consideration should be given to the fact that anesthesia may slow the heart rate, depress respiration and lower
blood pressure (Gandomani et al, 2011).

**Traumatic brain injury and anatomical variables**

The majority of pigs (83%) in this study when euthanized using a penetrating captive bolt experienced bolt penetration in the frontal part of the brain. The mature weight class pigs (200 + kg) saw more variation in the location and incidence of non-penetrations.

Due to an unbalanced sample distribution of skull shapes it was not feasible to assess the influence skull shape had, not only on the location of penetration by the bolt into the brain, but also if the skull shape affected the ability for the bolt to penetrate the brain. Skull shape is believed to be associated with inconsistency in application of a captive bolt gun as the target area is very small and can be exacerbated by the dished forehead found in certain breeds and in aged pigs, especially sows (EFSA, 2004). A future study should focus on the anatomical differences between skull shapes and the effect that the shape of the skull has on the location of penetration in mature animals.

Postmortem examinations have shown that head injuries are likely to be instantly fatal when hemorrhage occurs in the brain stem (Gregory, 2004). The desired outcome is the death of the brainstem, which is the central control for respiration. Through cessation of respiration, the heartbeat will cease, stopping the flow of blood and oxygen to the brain which results in the death of the brain and the animal. There are 4 specific regions of the brain that control respiration, 2 in the medulla which regulate inspiration, the basic rhythm of breathing and expiration (Reece, 2004). The other 2 are located in the pons and they regulate inspiratory volume, respiratory rate and stimulate of the medulla. The regions evaluated for the presence of hemorrhaging in the general area of the brain stem included the thalamus, pons, medulla and cerebellum.
The cerebral cortex was the only area of the brain evaluated for traumatic brain injury in which damage was recorded in all weight classes, though the severity of damage differed with pig maturity. The cerebral cortex is responsible for higher order functions such as language, memory, attention, emotion, problem solving (Niewenhuys, et al 1998) for this reason traumatic brain injury to this anatomical brain region is not a reliable indicator for evaluating the effectiveness of any mechanical method of euthanasia. Lack of direct damage to the thalamus, medulla, cerebellum and pons was due to the fact that the bolt was unable to penetrate into these deeper anatomical regions of the brain, yet animals were still effectively euthanized. These results were consistent with a similar trial evaluating traumatic brain injury in horses euthanized with a free bullet (Millar and Mills, 2000). All horses had traumatic brain injury to the cerebral cortex, with the vast majority of horses showing no damage to the other assessed regions.

Since traumatic brain injury was only visually assessed at a macroscopic level for abnormalities, the presence and degree of microscopic lacerations and axonal injury due to the tearing and shearing caused by the concussive force were not accounted for. Mechanical methods of euthanasia rely heavily on this microscopic level of brain damage for effectiveness (EU Scientific Veterinary Committee, 1997), especially to the brainstem which is the central control for respiration (Reece, 2004). This likely explains why pigs consistently died after application of the penetrating captive bolt gun, although visual traumatic brain injury to the thalamus, cerebellum, medulla and pons was only present in one pig euthanized with the penetrating bolt. Although current results from this study did not show an association between macroscopic traumatic brain injury and effective euthanasia it would be useful to pursue histological work that might reveal more subtle
differences. Future development of captive bolt gun technology may benefit from a clearer understanding of the effects of the concussive force delivered by a captive bolt gun in relation to death in comparison to the damage caused by direct penetration of the brain.

For the pigs euthanized with the non-penetrating captive bolt gun, traumatic brain injury was present in all regions of the brain, though level of traumatic brain injury did vary among some of the pigs. In many of the pigs total destruction of the brain did occur.

All pigs had hemorrhaging in the brainstem and cerebellum with 41 and 40 (98 and 95%) displaying hemorrhaging in the thalamus and pons/medulla respectively. Since the 2 animals that did not display hemorrhaging in the pons and medulla were ones requiring a secondary method, it may be implied that microscopic damage and hemorrhaging in these 2 areas is critical to effective euthanasia, but the sample size from the current trial is too small. Hemorrhaging can be used in future trials to further assess the concussive force of the captive bolt gun, the resulting hemorrhaging and its relationship to effective euthanasia.

Conclusions

With proper application and correct selection of bolt length and cartridge size, the “CASH” dispatch kit is an effective one step euthanasia method for pigs under 200 kg. However once pigs weighed 200 kg or more, the effectiveness and reliability of this method was not consistent. Future research would be beneficial on the effect skull shape and skull bone densities have on the effectiveness of the captive bolt gun and the proper placement of the gun for accurate penetration in heavier pigs. Microscopic damage caused by concussion and its relationship to effective euthanasia would also be a
worthwhile study to allow for further advancements in the development of captive bolt guns.

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Table 2.1. Weight classes, sex and skull shapes provided to farm staff for selection of 42 pigs for the trial.

<table>
<thead>
<tr>
<th>Weight Class</th>
<th>No. pigs $^a$</th>
<th>Sex</th>
<th>Skull Shape $^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (2 to 3 kg)</td>
<td>6</td>
<td>Female (n= 3) Male (n=3)</td>
<td>Dish and Plank</td>
</tr>
<tr>
<td>2 (7.5 to 10 kg)</td>
<td>6</td>
<td>Female (n= 3) Male (n=3)</td>
<td>Dish and Plank</td>
</tr>
<tr>
<td>3 (15 to 20 kg)</td>
<td>6</td>
<td>Female (n= 3) Male (n=3)</td>
<td>Dish and Plank</td>
</tr>
<tr>
<td>4 (30 to 40 kg)</td>
<td>6</td>
<td>Female (n= 3) Male (n=3)</td>
<td>Dish and Plank</td>
</tr>
<tr>
<td>5 (100 to 120 kg)</td>
<td>6</td>
<td>Female (n= 3) Male (n=3)</td>
<td>Dish and Plank</td>
</tr>
<tr>
<td>6 (200 to 250 kg)</td>
<td>6</td>
<td>Female (n= 3) Male (n=3)</td>
<td>Dish and Plank</td>
</tr>
<tr>
<td>7 (300 kg+)</td>
<td>6</td>
<td>Female (n= 3) Male (n=3)</td>
<td>Dish and Plank</td>
</tr>
</tbody>
</table>

$^a$ Pigs were selected for euthanasia by farm staff, and enrolled in the study based on weight, sex and skull shape.

$^b$ Criteria presented to farm staff for selection of pigs for the trial.

Skull shape. A dish shape skull was defined as one that was short and broad. A plank face skull was defined as long narrow skull. Farm staff was asked to provide a variance in skull shapes for each of the weight classes.
Table 2.2: Count data for pigs by weight class, sex and skull shape.

<table>
<thead>
<tr>
<th>Weight Class&lt;sup&gt;b&lt;/sup&gt;</th>
<th>No. pigs</th>
<th>Sex</th>
<th>Dish Shape</th>
<th>Plank Face</th>
<th>Unclear</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (2 to 3 kg)</td>
<td>6</td>
<td>Female (n= 3)</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Male (n=3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 (7.5 to 10 kg)</td>
<td>6</td>
<td>Female (n= 3)</td>
<td>0</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Male (n=3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 (15 to 20 kg)</td>
<td>6</td>
<td>Female (n= 3)</td>
<td>0</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Male (n=3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 (30 to 40 kg)</td>
<td>6</td>
<td>Female (n= 3)</td>
<td>0</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Male (n=3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 (100 to 120 kg)</td>
<td>6</td>
<td>Female (n= 4)</td>
<td>1</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Male (n=2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6&lt;sup&gt;b&lt;/sup&gt; (200+ kg)</td>
<td>12</td>
<td>Female (n= 3)</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Male (n=3)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Skull shape. A dish shape skull was defined as one that was short and broad. A plank face skull was defined as long narrow skull. Unclear were face shapes that were not obviously plank or dish shape.

<sup>b</sup> Following initial analyses of the data and distribution of the weight classes, the top 2 weight classes were merged into one weight class of mature pigs weighing 200+ kg.
Table 2.3. "CASH" Dispatch bolt types and stem diameters and lengths (Accles and Schevolke, Sutton Coldfield, West Midlands, UK).

<table>
<thead>
<tr>
<th>Muzzle type</th>
<th>Bolt Diameter (cm)</th>
<th>Stem Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Penetrating</td>
<td>3.8 (^a)</td>
<td>N/A (^b)</td>
</tr>
<tr>
<td>Short Bolt</td>
<td>1.2</td>
<td>12.2</td>
</tr>
<tr>
<td>Medium Bolt</td>
<td>1.2</td>
<td>15.5</td>
</tr>
<tr>
<td>Extended Bolt</td>
<td>1.2</td>
<td>17.4</td>
</tr>
</tbody>
</table>

\(^a\) 1.9 cm radius, 1151.1 cm\(^2\) area.

\(^b\) The non-penetrating head does not have a stem that extends from the muzzle and penetrates the skull.
Table 2.4. Coordination of muzzle type and cartridge to weight class of pig.

<table>
<thead>
<tr>
<th>Pig Weight Class</th>
<th>Muzzle Type</th>
<th>Cartridge Color&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Nominal Propellant Charge&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (2 - 3 kg)</td>
<td>Non-penetrating</td>
<td>Pink</td>
<td>135 mg</td>
</tr>
<tr>
<td>2 (7.5 - 10 kg)</td>
<td>Non-penetrating</td>
<td>Pink</td>
<td>135 mg</td>
</tr>
<tr>
<td>3 (15 - 20 kg)</td>
<td>Short Bolt</td>
<td>Yellow</td>
<td>160 mg</td>
</tr>
<tr>
<td>4 (30 - 40 kg)</td>
<td>Short Bolt</td>
<td>Yellow</td>
<td>160 mg</td>
</tr>
<tr>
<td>5 (100 - 120 kg)</td>
<td>Medium Bolt</td>
<td>Blue</td>
<td>210 mg</td>
</tr>
<tr>
<td>6 (200+ kg)</td>
<td>Extended Bolt</td>
<td>Orange</td>
<td>265 mg</td>
</tr>
</tbody>
</table>

<sup>a</sup> The tip of each cartridge is painted with the coordinating color of the nominal propellant charge for easy identification by users. (Accles and Schevolke, Sutton Coldfield, West Midlands, UK).

<sup>b</sup> The minimal force produced by expanding gas that propels the bolt out of the gun upon firing.
Table 2.5. Time to last heartbeat means (±SE) for the 6 weight classes of pigs and males and females.

<table>
<thead>
<tr>
<th>Statistics&lt;sup&gt;a&lt;/sup&gt;</th>
<th>No. Pigs</th>
<th>Mean (s)</th>
<th>Mean SE</th>
<th>Median (s)</th>
<th>Range (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weight Class</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (2 to 3 kg)</td>
<td>(n=6)</td>
<td>318.4</td>
<td>67.4</td>
<td>367.0</td>
<td>451.0</td>
</tr>
<tr>
<td>2 (7.5 to 10 kg)</td>
<td>(n=6)</td>
<td>284.0</td>
<td>29.0</td>
<td>296.1</td>
<td>182.7</td>
</tr>
<tr>
<td>3 (15 to 20 kg)</td>
<td>(n=6)</td>
<td>264.5</td>
<td>28.2</td>
<td>276.0</td>
<td>208.0</td>
</tr>
<tr>
<td>4 (30 to 40 kg)</td>
<td>(n=6)</td>
<td>237.8</td>
<td>56.3</td>
<td>293.0</td>
<td>350.0</td>
</tr>
<tr>
<td>5 (100 to 120 kg)</td>
<td>(n=6)</td>
<td>222.8</td>
<td>38.8</td>
<td>203.5</td>
<td>245.0</td>
</tr>
<tr>
<td>6 (200+ kg)</td>
<td>(n=8)</td>
<td>92.1</td>
<td>42.9</td>
<td>49.0</td>
<td>342.3</td>
</tr>
<tr>
<td><strong>Sex</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>(n=21)</td>
<td>212.9</td>
<td>28.3</td>
<td>173.9</td>
<td>380.0</td>
</tr>
<tr>
<td>Male</td>
<td>(n=17)</td>
<td>248.8</td>
<td>33.5</td>
<td>273.7</td>
<td>451.0</td>
</tr>
</tbody>
</table>

<sup>a</sup>The presence of a detectable heartbeat was palpated and latency for cessation of heartbeat was determined using a stopwatch. Once the heartbeat could no longer be palpated, a stethoscope was used to confirm cessation of heart rate.
Table 2.6. Pigs requiring electrocution as a secondary method of euthanasia at the 10 min ceiling for confirmation of death.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Weight Class</th>
<th>Face Shape</th>
<th>Eye blink Response&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Respiration 10:00 min&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Heartbeat 10:00 min&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Clonic Movement&lt;sup&gt;d&lt;/sup&gt;</th>
<th>Audible Noise&lt;sup&gt;e&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>(200+ kg)</td>
<td>Unclear</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>M</td>
<td>(200+ kg)</td>
<td>Dish</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>M</td>
<td>(200+ kg)</td>
<td>Unclear</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>F</td>
<td>(200+ kg)</td>
<td>Dish</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

<sup>a</sup> Light touching of the cornea with a finger to detect the presence of involuntary blinking.

<sup>b</sup> Observed visually and acoustically.

<sup>c</sup> Palpated directly behind the forearm, and latency for cessation of heartbeat was determined using a stopwatch. Once the heartbeat could no longer be palpated, a stethoscope was used to confirm cessation of heart rate.

<sup>d</sup> Repeated muscular spasms (i.e. kicking).

<sup>e</sup> Orally or nasally audible noises including gasps, groans or grunts. Sow #24 made 80 audible noises described as “snoring” sounds.
Table 2.7. The presence of hemorrhaging visually assessed in the 5 regions of the brain for the 4 pigs requiring a secondary method of euthanasia.

<table>
<thead>
<tr>
<th>Tag Number</th>
<th>Cerebral Cortex&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Thalamus&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Cerebellum&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Pons&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Medulla&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>17</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>16</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>24</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

<sup>a</sup>Hemorrhaging was documented as either present (Yes) or not present (No).
Table 2.8. Location of penetration within the brain and Traumatic Brain Injury (TBI) scores for the 4 pigs requiring a secondary method of euthanasia.

<table>
<thead>
<tr>
<th>Location of Penetration</th>
<th>Level of Traumatic Brain Injury&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cerebral Cortex TBI&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>F</td>
<td>1</td>
</tr>
<tr>
<td>N</td>
<td>0</td>
</tr>
<tr>
<td>N</td>
<td>0</td>
</tr>
<tr>
<td>O</td>
<td>2</td>
</tr>
</tbody>
</table>

<sup>a</sup> skulls were split longitudinally using knives, a bandsaw or a combination of both and location of penetration and TBI were visually assessed. Grossly normal (0), some abnormalities (1) and grossly abnormal/unrecognizable (2).

<sup>b</sup> Location of penetration was classified as Frontal (F), Occipital (O), Parietal (P) or No Penetration (N).
Table 2.9: Of the pigs successfully euthanized in a single step with the penetrating captive bolt, 24 had the bolt penetrate the frontal part of the brain.

<table>
<thead>
<tr>
<th>Weight Class</th>
<th>No. Pigs</th>
<th>Frontal</th>
<th>Parietal</th>
<th>Occipital</th>
<th>No Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 (15 to 20 kg)</td>
<td>(n=6)</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4 (30 to 40 kg)</td>
<td>(n=6)</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5 (100 to 120 kg)</td>
<td>(n=6)</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6 (200+ kg)</td>
<td>(n=8)</td>
<td>7</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 2.10. Level of traumatic brain injury to the cerebral cortex, thalamus, cerebellum, pons and medulla for the pigs euthanized with the non-penetrating head in the 2 lowest weight classes (2 – 10 kg).

<table>
<thead>
<tr>
<th>Region</th>
<th>0&lt;sup&gt;b&lt;/sup&gt;</th>
<th>1&lt;sup&gt;c&lt;/sup&gt;</th>
<th>2&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cerebral Cortex</td>
<td>0</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Thalamus</td>
<td>0</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Cerebellum</td>
<td>0</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Pons</td>
<td>0</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Medulla</td>
<td>0</td>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>

<sup>a</sup> All skin was cut away from the top of the skull and bone fractures removed with tweezers to expose the brain. The brain was then removed from the skull cavity.

<sup>b</sup> Grossly normal.

<sup>c</sup> Some abnormalities.

<sup>d</sup> Grossly abnormal/unrecognizable
CHAPTER 3: ANALYSIS OF THE USE OF THE “CASH” DISPATCH CAPTIVE BOLT GUN AS A SINGLE STEP EUTHANASIA PROCESS IN A SWINE COMMERCIAL PRODUCTION SETTING

A paper to be submitted to the Journal of Animal Science

ABSTRACT

The objective of this study was to analyze the effectiveness of the “CASH” Dispatch Kit as single step euthanasia method for all weight classes of pigs within a commercial setting. Males and females from six weight classes (2-3 kg, 7.5-10 kg, 15-20 kg, 30-40 kg, 100-120 kg, 200+ kg) were enrolled in the trial. Fifteen stockpersons were enlisted from a single production company to perform euthanasia. Four different captive bolt gun heads were utilized - a non-penetrating head, a short penetrating bolt, a medium penetrating bolt and an extended penetrating bolt. The 5 lightest weight class animals (2-120 kgs) were all effectively euthanized with a single application of the "Cash" Dispatch. In the heaviest weight class (200+ kg), 7 of the 60 pigs required a second shot. There was a difference between weight class and requirement for a second shot with all 7 occurring in the heaviest weight classes (p=0.0066). Three stockpersons accounted for the 7 failed single step euthanasia and of these, one stockperson was responsible for 4 failures.

Introduction

The American Veterinary Medical Association (AVMA, 2007) defines euthanasia as death that occurs with minimal pain and distress. The swine industry has the
responsibility that whenever the life of an animal is taken, it is done as painless and distress free as possible. This responsibility includes ensuring that caretakers have access to acceptable methods of euthanasia and training programs. The development of effective euthanasia methods and training material for producers has become a priority for swine industry groups such as the National Pork Board (NPB).

The characteristics of an effective euthanasia method is that it can be consistently used to cause death with minimum pain and distress in a single step as highlighted by the European Food Safety Association (EFSA) (2004) “Killing methods which induce unconsciousness and death either simultaneously or sequentially, and do not rely on bleeding to cause death should be preferred when available and proven to be effective”.

Effective euthanasia methods must also be safe for stockpersons.

Captive bolt guns are a mechanical method for swine euthanasia (AVMA 2007, American Association of Swine Veterinarians (AASV), 2009). Traditional captive bolt guns were designed for only stunning an animal in a slaughter environment. Most regulations, outside of the AVMA (2007), require that a secondary kill step accompany captive bolt gun application to ensure death (HSA, 2006; EFSA, 2004; OIE, 2007) and do not recognize captive bolt guns as a single step method.

Previous research on the effectiveness of the penetrating captive bolt gun as a single step euthanasia for cattle, sheep and water buffalo was not reliable (Daly et al., 1986; Daly et al., 1987; Finnie, 1993; Gregory et al., 2007; Gregory et al., 2009). A more recent study involving 489 sheep, found the penetrating captive bolt was effective when the trajectory was properly positioned (Gibson et al., 2012). Research exploring the use of a captive bolt gun as a single step method for euthanasia of swine, has been limited. Two
published papers on the use of the non-penetrating bolt gun found the method to not be reliable (Finnie et al., 2003; Widowski, 2008).

Therefore, the objectives of this study was to (1) determine the effectiveness of the “CASH” Dispatch Kit as single step euthanasia method on all weight classes of pigs and (2) to ascertain the repeatability of the “CASH” Dispatch Kit, across a variety of stockpersons in a commercial setting.

**Materials and Methods**

*Experimental design and treatments*

The experimental design was a 6*2 factorial arrangement of treatments. Treatments were weight class (1 through 6) and sex (female and male). The experimental unit was the individual pig.

*Animals*

Two hundred and nine commercial pigs from 5 integrated production sites within Missouri were enrolled in the trial. Pigs were selected by farm staff based on weight and sex (Table 3.1). Further criteria for the selection of pigs included variations in skull shapes (dish shape and plank shape) within the mature weight classes and that the animals should be cull animals with no damage, injury or deformity to the head. Seven weight classes were initially established to encompass all stages of production and extremities of size. Following initial analyses of the data and distribution of the weight classes, the top 2 weight classes were merged into one weight class of heavy pigs weighing 200+ kg.

*Enrollment and training of stockpersons*

Fifteen stockpersons from 1 company were enlisted from 5 production sites. The sites
included one farrowing unit, 1 nursery site, 2 finishing sites and a boar stud (Table 3.2). Previous experience of the stockpersons ranged from first time users to stockpersons who used captive bolt guns weekly.

Instruction was provided by 1 researcher to all stockpersons before each euthanasia session began. The instruction lasted ~20 min. The first part of the instruction included directions on how to load the gun, how to operate the safety and trigger mechanisms and how to remove the spent cartridge from the chamber. The second part of the instruction covered the euthanasia process including the requirement for all pigs to be restrained with a cable snare, ensuring the gun muzzle was held flush and perpendicular to the skull, the method for delivery if a secondary shot was required, criteria to determine if a second shot was needed and proper placement of the captive bolt on the skull. Stockpersons were instructed on pig anatomical placement based on the current industry guidelines. Originally left to the discretion of the stockperson, however snaring the pigs for restraint became a requirement following the euthanasia of the first 20 pigs on trial.

If a second penetrating bolt shot was required, stockpersons were immediately applied a second shot. If the first shot appeared to be accurately placed, the procedure was repeated but the tip of the muzzle was placed approximately 3 cm above the first penetration hole and approximately 1 cm to the left or right of the 1st penetrating hole. If the first shot was not accurately placed, they were instructed to place the gun in the correct location. For animals euthanized with the non-penetrating bolt, stockpersons were instructed to target the top of the head again.

"CASH" Dispatch Kit

The “CASH” Dispatch Kit (Accles and Schevolke, Sutton Coldfield, West Midlands, UK) is a heavy duty, .25 caliber cartridge propelled captive bolt device with
interchangeable muzzle assemblies. The unit provides 4 bolt head styles (Table 3.3) and 5 power cartridges and coordinated to bolt head type and weight class of the pig (Table 3.4).

**One step euthanasia methodology**

Pigs from weight classes 1 (2 - 3 kg) through 5 (100 - 120 kg), and the 30 sows from weight class 6 (200 + kg), were sorted out of pens for the trial by farm personnel. At the farrowing site, weight class 1 (2 - 3 kg) and the sows from weight class 6 (200 + kg) were sorted and loaded out of a barn and transported on a trailer across the road to an adjoining yard. The suckling pigs were removed from the trailer, restrained with a wire cable snare on a concrete pad and euthanized. The sows were all snared and euthanized on the trailers.

At the nursery site, weight classes 2 (7 - 10 kg) and 3 (15 - 20 kg) were transported from the pens by stockpersons in pushcarts to a central room in the barn for euthanasia. Weight class 4 (30 - 40 kg) and weight class 5 (100 - 120 kg) at the finishing barns were sorted out of pens by stockpersons into the central alley of the barn where they were snared and euthanized. The mature boars from weight class 6 (200 + kg) were constrained individually within rod iron chutes outside the barn that were constructed specifically for this trial. Only 10 of the 30 boars were snared for euthanasia.

Each stockperson was supplied with a captive bolt gun and the appropriate bolt head along with the coordinated power charges based on the manufacturers recommendations (Accles and Schevolke, Sutton Coldfield, West Midlands, UK). Twelve cartridges were provided, one for each of their 10 pigs and 2 extra cartridges in case a second shot was required. Once the animal was safely restrained with a cable snare, the gun was placed
perpendicular and firmly against the pigs’ skull in the proper location and fired.

**Confirmation of insensitivity and death**

Insensibility was confirmed by the immediate collapse of the animal, and touching the cornea with a finger to detect the presence of involuntary blinking. Once clonic kicking ceased and the researcher was able to safely approach the pig, the presence of a detectable heartbeat was palpated posterior to the foreleg, and cessation of heartbeat was determined using a stopwatch started upon application of the captive bolt gun. Presence of rhythmic breathing was observed visually and acoustically. Each pig was pronounced dead when both cessation of heartbeat and respiration was confirmed. A second shot was applied immediately if signs of sensibility were present including failure to collapse, and the presence of eye blink response.

Two researchers documented parameters including presence of eye blink response, sex of the pig, number of kicks (counted on one hind leg, recorded with a hand counter), number of orally or nasally audible noises (including voluntary or involuntary gasps, groans or grunts) and time to cessation of movement including twitching of the tail or snout. A third researcher documented casual observations about accuracy of the placement of the shot.

**Statistical Analysis**

Data was entered into Microsoft Office Excel 2004 (Microsoft, Redmond, Washington, USA) and verified against written data sheets. Statistical analysis was performed using Statistical Analysis Software (SAS, version 9.2; SAS Institute Inc., Cary, NC, USA).

The frequency of the requirement for second shot and explanatory factors such as
weight class and sex were calculated. The association between the requirement for second shot with potential explanatory variables weight class, sex and stockperson was assessed using a univariate logistic regression. Requirement for a second shot was the outcome of interest (yes or no). The categorical variables were weight class with 6 categories 2-3 kg, 7.5-10 kg, 15-20 kg, 30-40 kg, 100-120 kg, 200+ kg, sex (male, female) and stockperson, coded using their pre-assigned identification number. Quasi-separation of the datasets occurred with weight class and stockperson, so descriptive data was obtained using the frequency procedure. A P-value of ≤ 0.05 was considered to be significant for the association between the requirement for a second shot and sex.

The means for the continuous variables time to cessation of heartbeat, time to cessation of movement and number of kicks with the treatment effects sex and weight class were calculated and compared. A mixed effects regression procedure was then performed to assess the association between continuous variables, time to cessation of heartbeat, time to cessation of movement and number of kicks and the fixed treatment effects sex and weight class while controlling for stockperson as a random variable. A P-value of ≤ 0.05 was considered to be significant. Only animals euthanized with a single shot were included in these models.

Results

Effectiveness of one step euthanasia using a captive bolt gun

A total of 209 pigs in the trial were effectively euthanized (97%) with a single application of the "Cash" Dispatch Kit. One pig in weight class 1 (2-3 kg) was removed from the trial due to a suspected faulty cartridge during euthanasia. Seven pigs (2 sows and 5 boars) in weight class 6 (200+ kg) required a second shot. There was no difference between sexes and the requirement for a second shot (P=0.48).
The first group of animals that were euthanized for this trial comprised 30 boars at the boar stud. The first 2 stockpersons had difficulty with accurate placement of the gun as the boars were continually moving their heads. After these first 2 groups of boars (n=20), of which 5 required a second shot, snaring was made a requirement for all pigs in the trial. Inaccurate application or placement of the gun was noted through casual observation for 5 of the 7 pigs. These data are presented in Table 3.5.

**Confirmation of insensibility and death**

Eyeblink response following the first shot was present in 4 boars, of which all 4 required a second shot (Table 3.5). Respiration, rhythmic or non-rhythmic, was observed in 7 pigs. Four of those 7 animals did require a second shot due to presence of eyeblink response while the remaining 3 were effectively euthanized with a single application.

The mean for time to cessation of heartbeat was 180.9 s (± 9.5 SE). There was a difference between the weight classes and time to cessation of heartbeat (P= 0.0066). Heavier animals had longer times to cessation of heartbeat however there was not a consistent pattern in the differences with weight class 2 (7.5 - 10 kg) showing the longest mean time and weight class 5 (100 - 120 kg) showing the shortest. For the variable time to cessation of heartbeat there was no association with between sex (P=0.41;Table 3.6).

The mean time to last movement was 180.0 s (± 7.0 SE), at times occurring after cessation of heartbeat. There was an association between weight classes (P=<0.0001) and sex (P=0.0093) for time to last movement (Table 3.7). The mean number of kicks was 116.6 s (± 3.5 SE) with a range from 14 to 361. There was no evidence of an association between the weight classes (P=0.15) or sex (P=0.25) and mean number of kicks (Table 3.8).
Audible sounds were recorded within all weight classes euthanized with the penetrating bolt. The audible noises ranged from a single sound up to 30 “noises” with no distinction made on the type or length of sounds. Audible noises were documented equally between the use of the non-penetrating head and the penetrating heads. Of these 30 pigs that expressed audible noises, 5 required a secondary shot, but the remaining 25 were effectively euthanized with a single application.

**Discussion**

Traditional captive bolt guns were designed for only stunning an animal in a slaughter environment. Most regulations, outside of the AVMA (2007), require that a secondary kill step accompany captive bolt gun application to ensure death (HSA 2006, EFSA 2004, OIE 2007) and do not recognize captive bolt guns as a single step method.

The “CASH” Dispatch Kit successfully euthanized 96.7% (202/209) of the pigs in a single step when all 6 weight classes were combined. When weight classes were assessed individually 100 % of the pigs in weight classes 1 – 5 were euthanized with a single application, but weight class 6 (200kg+) saw only 53/60 (88%) successfully euthanized in one application. Of the 7 not euthanized with one shot, 5 could perhaps be attributed to the lack of restraint of the animal, which can lead to improper placement. Previous research by the authors found upon assessment of the brain, incorrect placement of the gun was responsible for failed single step euthanasia (Chapter 2) and recent research on 489 sheep (Gibson, et al., 2012) found that 100% (n=28) of the sheep that showed incomplete concussion were found to have been shot incorrectly.

The prevalence of insensibility in the heaviest class of animals when not restrained was 5 / 20 (25%) and 2/40 (5%) when the animals were restrained. However, this
inference is speculative, because of the potential for confounding of 1) weight class, 2) lack of restraint and 3) stockperson. However, the hypothesis that restraint leading to incorrect placement may be the mechanism of failure is consistent with other research findings including Finnie (1993) and (Gibson et al., 2012) who both recommend that sheep be restrained during application of the captive bolt gun to ensure proper placement of the gun. Dissection of the brain would be required for confirmation of location of penetration and accuracy of the shot.

Common death parameters include cessation of respiration, absence of papillary light reflex, the corneal reflex, cessation of heartbeat and the gag reflex (Gregory, 1998; EFSA, 2004). The cessation of rhythmic breathing and the onset of respiratory paralysis (apnoea) are the most definitive signs of brainstem death. When the brainstem ceases to function, respiration will also stop (Adams and Sheridan, 2008). The cessation of respiration will lead to the heartbeat ceasing, resulting in the termination of all brain activity. Respiration is used as an indicator of sensibility in pigs (Grandin, 1998; HSA, 2006; AASV, 2009; ) in the form of rhythmic breathing.

The presence of respiration in 3 pigs that were effectively euthanized with one shot was noted to just over 3 min in 1 pig, and lasting just over 2 min in the remaining pigs, with no other signs of sensibility noted. This indicates that the cessation of respiration though rare, may not always cease immediately, though the animal has been effectively euthanized. No previous literature could be found comparing time to cessation of heartbeat between weight class of animals or sex.

Time to cessation of movement varied across weight classes, which is consistent with previous research that found a difference in the duration of leg movement with pig size.
and method of euthanasia (manual blunt force versus mechanical blunt force). Newborn piglets showed a longer duration of leg spasms than larger (up to 9 kg) anesthetized piglets (Casey-Trott et al., 2010). In a separate trial (Widowski, 2008), found piglets euthanized with a non-penetrating captive bolt gun, showed more leg movement than pigs euthanized by manual blunt force trauma. It is not possible from our experimental results to determine if these differences relate to the degree of traumatic brain injury or a physiological difference between the maturity levels of the weight classes.

This study is the first to document the intensity and duration of clonic movements in unanesthetized pigs. The number of kicks following euthanasia is of most value for educational purposes. Clonic movement should not to be mistaken as an expression of pain or sensibility. Following euthanasia, pigs will exhibit a brief tonic stage followed by clonic movement (AASV, 2009). Effective concussion stunning leads to tonic and clonic seizures, and therefore the occurrence of generalized seizures has been used as a sign of unconsciousness (Shaw, 2002) and is an early indicator of early brain failure leading to death (Gibson, et al., 2012). The HSA (2006) also lists paddling and involuntary kicking as a sign of a successful stun. We were unable to identify other research that documented or collected data comparing sex and number of kicks following euthanasia. As with time to last movement, these differences may be a physiological difference between the sexes or may relate to differences in the maturity in the weight classes.

Normally, “vocalization” is used to assess whether stunning was properly applied in a slaughter facility or if a pig was “hot-wanded” during electric stunning (Grandin, 1998, AMI, 2010). These are very distinct squeals that are an indicator of pain or sensibility and do not include sounds that can occur due to the exhaust of air from the lungs, a normal
grunting sound that may occur from the impact of the captive bolt gun or noises that occur during the violent kicking during the clonic stage. The AASV (2009) reported that involuntary vocalization can occur during the application of CO₂ and Grandin (2004) reports gasping and gagging reflexes can be a normal response to captive bolt gun euthanasia. Of the 30 pigs that expressed some type of audible sound, only 3 of them required a second shot. Type of audible noise was not noted by either of the observers, just the number of sounds exhibited. For educational purposes, stockpersons can be made aware that insensible animals may express audible noises during euthanasia.

**Conclusion**

The “CASH” Dispatch Kit is a reliable method for single step euthanasia for pigs weighing less than 200 kg. However for pigs that weighed 200 kg or more, the effectiveness and reliability of this method was not consistent. Standard operating procedures for euthanasia should include restraining the animal before euthanasia, the proper selection of heads and cartridges and confirmation of death before walking away or moving the animal. Training programs must not only include how to properly administer euthanasia and confirmation of death, but also an understanding of the process of death and what the stock handlers can expect following application of the “CASH” Dispatch Kit.

**References**


AASV. American Association of Swine Veterinarians & National Pork Board. 2009
On Farm Euthanasia of Swine; Recommendations for the Producer. National Pork Board, Des Moines, IA, USA, document 04259-01/09.


OIE. World Organization for Animal Health. 2007. Guidelines for the Killing of


Table 3.1 Two hundred and ten commercial pigs from 5 integrated production sites within Missouri enrolled in the trial. Pigs were selected by farm staff, based on weight and sex.

<table>
<thead>
<tr>
<th>Weight Class</th>
<th>Weight Range</th>
<th># of pigs</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(^a)</td>
<td>2 - 3 kgs</td>
<td>29</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>7 - 10 kgs</td>
<td>30</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>15 - 20 kgs</td>
<td>30</td>
<td>7</td>
<td>23</td>
</tr>
<tr>
<td>4</td>
<td>30 - 40 kgs</td>
<td>30</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>100 - 120 kgs</td>
<td>30</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>6(^b)</td>
<td>200 + kgs</td>
<td>60</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

\(^a\) One pig in weight class 1 (2-3 kgs) was removed from the trial due to a suspected faulty cartridge during euthanasia.

\(^b\) Seven weight classes were initially established to encompass all stages of production but following initial analyses of the data and distribution of the weight classes, the top 2 weight classes were merged into one weight class of mature pigs weighing 200+ kg.
Table 3.2 Stockperson identification, weight class of pigs they euthanized, type of production site they were based at and total number of pigs they euthanized.

<table>
<thead>
<tr>
<th>Stockperson&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Weight Class</th>
<th>Production Site ID</th>
<th># of Pigs</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>5 (100 - 120 kg)</td>
<td>Finishing (1)</td>
<td>10</td>
</tr>
<tr>
<td>12</td>
<td>5 (100 - 120 kg)</td>
<td>Finishing (1)</td>
<td>10</td>
</tr>
<tr>
<td>13</td>
<td>5 (100 - 120 kg)</td>
<td>Finishing (1)</td>
<td>10</td>
</tr>
<tr>
<td>21</td>
<td>4 (30 - 40 kg)</td>
<td>Finishing (2)</td>
<td>10</td>
</tr>
<tr>
<td>22</td>
<td>4 (30 - 40 kg)</td>
<td>Finishing (2)</td>
<td>10</td>
</tr>
<tr>
<td>23</td>
<td>4 (30 - 40 kg)</td>
<td>Finishing (2)</td>
<td>10</td>
</tr>
<tr>
<td>31</td>
<td>2 (7 - 10 kg) and 3 (15 - 20 kg)</td>
<td>Nursery (3)</td>
<td>20</td>
</tr>
<tr>
<td>32</td>
<td>2 (7 - 10 kg) and 3 (15 - 20 kg)</td>
<td>Nursery (3)</td>
<td>20</td>
</tr>
<tr>
<td>33</td>
<td>2 (7 - 10 kg) and 3 (15 - 20 kg)</td>
<td>Nursery (3)</td>
<td>20</td>
</tr>
<tr>
<td>41</td>
<td>1 (2 - 3 kgs) and 6 (200 + kg)</td>
<td>Farrowing (4)</td>
<td>19</td>
</tr>
<tr>
<td>42</td>
<td>1 (2 - 3 kgs) and 6 (200 + kg)</td>
<td>Farrowing (4)</td>
<td>20</td>
</tr>
<tr>
<td>43</td>
<td>1 (2 - 3 kgs) and 6 (200 + kg)</td>
<td>Farrowing (4)</td>
<td>20</td>
</tr>
<tr>
<td>51</td>
<td>6 (200 + kg)</td>
<td>Boar Stud (5)</td>
<td>10</td>
</tr>
<tr>
<td>52</td>
<td>6 (200 + kg)</td>
<td>Boar Stud (5)</td>
<td>10</td>
</tr>
<tr>
<td>53</td>
<td>6 (200 + kg)</td>
<td>Boar Stud (5)</td>
<td>10</td>
</tr>
</tbody>
</table>

<sup>a</sup> Stockpeople were identified by the number assigned to their site (first digit) and the stockperson number they were assigned (second digit).
Table 3.3. "CASH" Dispatch Kit bolt types and stem diameters and lengths (Accles and Schevolke, Sutton Coldfield, West Midlands, UK).

<table>
<thead>
<tr>
<th>Muzzle type</th>
<th>Bolt Diameter (cm)</th>
<th>Stem Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Penetrating</td>
<td>3.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>N/A&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Short Bolt</td>
<td>1.2</td>
<td>12.2</td>
</tr>
<tr>
<td>Medium Bolt</td>
<td>1.2</td>
<td>15.5</td>
</tr>
<tr>
<td>Extended Bolt</td>
<td>1.2</td>
<td>17.4</td>
</tr>
</tbody>
</table>

<sup>a</sup> 1.9 cm radius, 1151.1 cm² area.

<sup>b</sup> The non-penetrating head does not have a stem that extends from the muzzle and penetrates the skull.
Table 3.4. Coordination of muzzle type and powerload to weight class of pig.

<table>
<thead>
<tr>
<th>Pig Weight Class</th>
<th>Muzzle Type</th>
<th>Cartridge Color&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Charge&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (2 - 3 kg)</td>
<td>Non-penetrating</td>
<td>Pink</td>
<td>135 mg</td>
</tr>
<tr>
<td>2 (7.5 - 10 kg)</td>
<td>Non-penetrating</td>
<td>Pink</td>
<td>135 mg</td>
</tr>
<tr>
<td>3 (15 - 20 kg)</td>
<td>Short Bolt</td>
<td>Yellow</td>
<td>160 mg</td>
</tr>
<tr>
<td>4 (30 - 40 kg)</td>
<td>Short Bolt</td>
<td>Yellow</td>
<td>160 mg</td>
</tr>
<tr>
<td>5 (100 - 120 kg)</td>
<td>Medium Bolt</td>
<td>Blue</td>
<td>210 mg</td>
</tr>
<tr>
<td>6 (200+ kg)</td>
<td>Extended Bolt</td>
<td>Orange/Black&lt;sup&gt;c&lt;/sup&gt;</td>
<td>265 mg/295 mg</td>
</tr>
</tbody>
</table>

<sup>a</sup>The tip of each cartridge is painted with the coordinating color of the nominal propellant charge for easy identification by users. (Accles and Schevolke, Sutton Coldfield, West Midlands, UK)

<sup>b</sup>The minimal force produced by expanding gas that propels the bolt out of the gun upon firing.

<sup>c</sup>A black cartridge was used on the larger pigs within weight class 6 at the discretion of the researcher based on visual assessment of weight.
Table 3.5 Seven mature pigs in weight class 6 (200+kg) required a second shot.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Stockperson&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Respiration&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Eyeblink Response&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Animal Snared</th>
<th>Correct Targeting&lt;sup&gt;d&lt;/sup&gt;</th>
<th>Cartridge Used&lt;sup&gt;e&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>43</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Black</td>
</tr>
<tr>
<td>F</td>
<td>43</td>
<td>Yes&lt;sup&gt;f&lt;/sup&gt;</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Orange</td>
</tr>
<tr>
<td>M</td>
<td>51</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Black</td>
</tr>
<tr>
<td>M</td>
<td>51</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Black</td>
</tr>
<tr>
<td>M</td>
<td>51</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Black</td>
</tr>
<tr>
<td>M</td>
<td>51</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Orange</td>
</tr>
<tr>
<td>M</td>
<td>52</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Black</td>
</tr>
</tbody>
</table>

<sup>a</sup> Stockpersons were identified by the number assigned to their site (first digit) and the stockperson number they were assigned (second digit).

<sup>b</sup> If respiration was still visible or audible following first application of captive bolt gun.

<sup>c</sup> Light touching of the cornea with a finger to detect the presence of involuntary blinking.

<sup>d</sup> Correct placement based on landmark and flushness of the muzzle to the skull was assessed visually by the researcher.

<sup>e</sup> The tip of each cartridge is painted with the coordinating color of the nominal propellant charge for easy identification by users. (Accles and Schevolke, Sutton Coldfield, West Midlands, UK). Orange cartridges have a propellant charge of 265 mg and blacks 295 mg.

<sup>f</sup> Exhalation of air in rhythm with kicking, not rhythmic breathing.
Table 3.6. Time to last heartbeat means (±SE) for the 6 weight classes of pigs and males and females euthanized with a single shot.

<table>
<thead>
<tr>
<th>Weight Class</th>
<th>No. Pigs</th>
<th>Mean (s)</th>
<th>Mean SE</th>
<th>Median (s)</th>
<th>Range (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (2 to 3 kg)</td>
<td>(n=29)</td>
<td>221.6</td>
<td>21.4</td>
<td>227.0</td>
<td>410.0</td>
</tr>
<tr>
<td>2 (7.5 to 10 kg)</td>
<td>(n=30)</td>
<td>242.2</td>
<td>24.5</td>
<td>230.5</td>
<td>501.0</td>
</tr>
<tr>
<td>3 (15 to 20 kg)</td>
<td>(n=30)</td>
<td>197.3</td>
<td>18.2</td>
<td>200.5</td>
<td>407.0</td>
</tr>
<tr>
<td>4 (30 to 40 kg)</td>
<td>(n=30)</td>
<td>161.6</td>
<td>19.2</td>
<td>175.5</td>
<td>340.0</td>
</tr>
<tr>
<td>5 (100 to 120 kg)</td>
<td>(n=30)</td>
<td>137.2</td>
<td>20.6</td>
<td>185.5</td>
<td>290.0</td>
</tr>
<tr>
<td>6 (200+ kg)</td>
<td>(n=53)</td>
<td>150.01</td>
<td>23.4</td>
<td>0.00</td>
<td>474.0</td>
</tr>
</tbody>
</table>

**Sex**

<table>
<thead>
<tr>
<th></th>
<th>No. Pigs</th>
<th>Mean (s)</th>
<th>Mean SE</th>
<th>Median (s)</th>
<th>Range (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>(n=117)</td>
<td>187.2</td>
<td>11.5</td>
<td>199.0</td>
<td>380.0</td>
</tr>
<tr>
<td>Male</td>
<td>(n=85)</td>
<td>172.1</td>
<td>16.2</td>
<td>206.0</td>
<td>474.0</td>
</tr>
</tbody>
</table>

*a* The presence of a detectable heartbeat was palpated directly behind the forearm, and latency for cessation of heartbeat was determined using a stopwatch. Once the heartbeat could no longer be palpated, a stethoscope was used to confirm cessation of heart rate.
Table 3.7. Time to last movement means (±SE) for the 6 weight classes of pigs and males and females euthanized with a single shot.

<table>
<thead>
<tr>
<th>Weight Class</th>
<th>No. Pigs</th>
<th>Mean (s)</th>
<th>Mean SE</th>
<th>Median (s)</th>
<th>Range (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (2 to 3 kg)</td>
<td>(n=29)</td>
<td>152.1</td>
<td>8.6</td>
<td>132.0</td>
<td>194.0</td>
</tr>
<tr>
<td>2 (7.5 to 10 kg)</td>
<td>(n=30)</td>
<td>174.0</td>
<td>12.8</td>
<td>166.5</td>
<td>269.0</td>
</tr>
<tr>
<td>3 (15 to 20 kg)</td>
<td>(n=30)</td>
<td>105.1</td>
<td>5.0</td>
<td>95.5</td>
<td>98.0</td>
</tr>
<tr>
<td>4 (30 to 40 kg)</td>
<td>(n=30)</td>
<td>147.8</td>
<td>16.5</td>
<td>112.5</td>
<td>347.0</td>
</tr>
<tr>
<td>5 (100 to 120 kg)</td>
<td>(n=30)</td>
<td>170.8</td>
<td>18.7</td>
<td>152.0</td>
<td>457.0</td>
</tr>
<tr>
<td>6 (200+ kg)</td>
<td>(n=53)</td>
<td>264.3</td>
<td>14.9</td>
<td>250.0</td>
<td>527.0</td>
</tr>
</tbody>
</table>

Sex

<table>
<thead>
<tr>
<th>Sex</th>
<th>No. Pigs</th>
<th>Mean (s)</th>
<th>Mean SE</th>
<th>Median (s)</th>
<th>Range (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>(n=117)</td>
<td>163.6</td>
<td>7.6</td>
<td>139.0</td>
<td>380.0</td>
</tr>
<tr>
<td>Male</td>
<td>(n=85)</td>
<td>202.5</td>
<td>12.6</td>
<td>169.0</td>
<td>572.0</td>
</tr>
</tbody>
</table>

\(^a\) Latency for cessation of movement including twitching of the tail or snout and was determined using a stopwatch.
Table 3.8. Average number of kicks for the 6 weight classes of pigs and males and females euthanized with a single shot.

<table>
<thead>
<tr>
<th>Weight Class</th>
<th>No. Pigs</th>
<th>Mean (s)</th>
<th>Mean SE</th>
<th>Median (s)</th>
<th>Range (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (2 to 3 kg)</td>
<td>(n=29)</td>
<td>142.3</td>
<td>5.6</td>
<td>143.0</td>
<td>150.0</td>
</tr>
<tr>
<td>2 (7.5 to 10 kg)</td>
<td>(n=30)</td>
<td>138.6</td>
<td>8.5</td>
<td>141.5</td>
<td>173.0</td>
</tr>
<tr>
<td>3 (15 to 20 kg)</td>
<td>(n=30)</td>
<td>113.7</td>
<td>4.3</td>
<td>107.5</td>
<td>95.0</td>
</tr>
<tr>
<td>4 (30 to 40 kg)</td>
<td>(n=30)</td>
<td>101.9</td>
<td>5.6</td>
<td>94.50</td>
<td>140.0</td>
</tr>
<tr>
<td>5 (100 to 120 kg)</td>
<td>(n=30)</td>
<td>105.2</td>
<td>6.4</td>
<td>99.5</td>
<td>170.0</td>
</tr>
<tr>
<td>6 (200+ kg)</td>
<td>(n=53)</td>
<td>102.7</td>
<td>9.6</td>
<td>85.0</td>
<td>347.0</td>
</tr>
</tbody>
</table>

Sex

<table>
<thead>
<tr>
<th>Sex</th>
<th>No. Pigs</th>
<th>Mean (s)</th>
<th>Mean SE</th>
<th>Median (s)</th>
<th>Range (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>(n=117)</td>
<td>104.0</td>
<td>4.3</td>
<td>100.0</td>
<td>222.0</td>
</tr>
<tr>
<td>Male</td>
<td>(n=85)</td>
<td>133.9</td>
<td>5.2</td>
<td>126.0</td>
<td>298.0</td>
</tr>
</tbody>
</table>

*The number of kicks was counted on one hind leg and tallied with a hand counter.*
CHAPTER 4: GENERAL SUMMARY AND CONCLUSIONS

The swine industry has struggled with ensuring effective euthanasia for many years and the pressure to develop effective euthanasia tools and training material for producers has increased significantly. For the past several years the National Pork Board (NPB) has prioritized the need for research related to euthanasia in their call for requests for proposals in the area of animal welfare. Currently, the American Veterinary Medical Association (AVMA, 2007) and American Association of Swine Veterinarians (AASV, 2009) recognizes inhalants, barbiturate overdose, penetrating captive bolt gun, blow to the head, gunshot and electrocution as acceptable means for euthanasia of swine. Each of these methods has limitations which highlight the need for new technology for the euthanasia of pigs.

Traditional penetrating and non-penetrating captive bolt guns were designed with the intent to only “stun” an animal during the slaughtering process (Temple Grandin, Colorado State University, Boulder, CO, USA, personal communication). For this reason most regulations require that a secondary kill (bleeding or pithing) step be applied immediately following stunning to ensure death (HSA, 2006; EFSA, 2004; OIE, 2007), limiting its acceptance as a single step method. Research relating to the euthanasia of swine using a captive bolt gun has been extremely limited with no primary research published on the use of the penetrating gun on swine and the researcher could find only 3 published papers related to swine and euthanasia with a non-penetrating captive bolt gun (Finnie, et al. 2003; Widowski, 2008, Casey- Trott, et al, 2010). Despite these 2 facts, the captive bolt gun has been widely used on commercial swine farms as a single step method of euthanasia for years.
In 2007, British manufacturer Accles and Schevolke (A&S), (Sutton Coldfield, West Midlands, UK) and its North American distributor, Bunzl Processor Division (St. Louis, Missouri, USA) embarked upon developing a system specifically designed for the single step euthanasia of swine in commercial operations. The results of this venture was the “CASH” Dispatch Kit, a heavy duty, .25 caliber cartridge propelled captive bolt device with interchangeable muzzle assemblies.

The overall objective of this thesis was to evaluate the effectiveness of the single stage captive bolt euthanasia method, the “CASH” Dispatch Kit on all weight classes of pigs. This study was the first of its kind to collect empirical data on the euthanasia of swine in all weight classes, in both a controlled laboratory setting and in a commercial field setting.

**Overview of Results**

The research objective for the first part of this study was to analyze the effectiveness the "CASH" Dispatch Kit for single step euthanasia of anesthetized pigs from all weight classes. This trial would also provide analyses of the effectiveness of the device for producing traumatic brain injury to specific regions of the brain, relative to weight class, skull shape and sex. All 30 pigs (100%) in the 5 lowest weight classes (2 kgs -120 kgs) were euthanized with a single application, while only 8 of the 12 (66%) pigs in the upper mature weight class (200+ kg) were effectively euthanized with the “CASH” Dispatch Kit. With proper application and correct selection of bolt length and cartridge size, the “CASH” dispatch kit was an effective single step euthanasia method for pigs weighing less than 200 kg. However once pigs weighed 200 kg or more, the effectiveness and reliability of this method was not consistent.
The research objective for the second part of this study addressed the effectiveness of the “CASH” Dispatch Kit as single step euthanasia method for all weight classes of pigs within a commercial setting. Two hundred and nine commercial pigs, representing 6 weight classes, from 5 different production sites in Missouri were utilized in this experimental design. All 149 pigs in the 5 lowest weight classes (2-120 kgs) were euthanized with a single application of the “CASH” Dispatch Kit. Only 53 of the 60 pigs (88.3%) in the upper weight class of mature animals were effectively euthanized with one application of the “CASH” Dispatch Kit. Two of the pigs requiring a second shot were sows, while the remaining 5 were boars. Like Chapter 2 of this thesis, the “CASH” Dispatch Kit was reliable for euthanizing pigs under 200 kg with a single application, but was not as consistently reliable in pigs over 200 kg.

Only 3 different stockpersons accounted for the 7 failed single step euthanasia, and 1 stockperson was responsible for 4 of those 7. All 5 of the failed boars were also not restrained with a snare during application of the gun. HSA (2006) and EFSA (2004) recommend that pigs be restrained, in particularly by their head, during the application of the captive bolt gun in order to ensure accurate placement of the gun and effective euthanasia. Finnie (1993) also concluded that head restraint is critical to the effectiveness of the captive bolt gun on sheep.

Secondary objectives of this thesis included the evaluation of differences within death parameters including time to cessation of heartbeat, time to last movement and number of kicks. Both trials showed a statistical difference between weight class and time to cessation of heartbeat. The anesthesized pigs had a longer mean to cessation of heartbeat (236 s) compared to the on farm pigs (180.9 s). There also was an inconsistency between
the mean times and weight classes. For the anesthetized pigs, the mean time decreased as the weight class increased. For the on farm trials, weight class 2 (7.5 - 10 kg) had the longest mean while weight class 5 (100 - 120 kg) showed the shortest mean time. There also was a difference between the sexes, as boars had the longest mean time to cessation of heartbeat in the anesthetized trials, with sows showing the longest mean time for the on farm trials.

Number of kicks and time to last movement was only documented during the on farm trials. There was no association between weight class or sex and number of kicks, though males did have a higher mean number of kicks than females and the mean number of kicks decreased as the weight classes increased. There was an association between time to last movement and both sex and weight class. Males exhibited a longer mean time to last movement then females, while weight class 6 (200+ kg) had the longest mean compared to weight class 3 (15-20kg) with the shortest mean. These statistics were unexpected and the researchers do not have an explanation for them other than a difference in physiology.

This is information that can be beneficial for extension work with producers. It provides a better understanding of the death process and can prepare stockpersons on what to expect during euthanasia and what physical reactions would be considered “normal” following application of a captive bolt gun. As an example, people are quite often taken aback by the violent kicking that occurs with a captive bolt gun, at times mistaking the clonic kicking as an indication of sensibility. Whereas, this data suggests that violent kicking may actually be an indicator of successful euthanasia, and the lack of clonic kicking may be an indicator of an ineffective shot. This is an area that is greatly
lacking in current training material and euthanasia literature.

Of the 4 anesthesized pigs that required a secondary method, 2 were categorized as dish shape and 2 as unclear. All plank face animals were successfully euthanized with one step. The difficulties with the non-plank face animals was not surprising to the researchers as one of the reasons for documenting skull shape was to further investigate the validity of the industry wide belief that dish face animals are more difficult to euthanize with a captive bolt (EFSA, 2004). This was a very small data set as skull shapes were not documented in the commercial trials and a larger trial would provide more accurate statistical analyses. It would be beneficial to the industry to continue to collect data on the skull differences and further investigate the need to possibly base the target location for captive bolt gun on skull shape and maturity of the animal, versus having one target location for all weight classes and skull shapes.

**Implications for swine production**

With the current limitations on acceptable methods of euthanasia of swine, the ever-increasing concern of the consuming public and targeting by animals rights organizations, the pressure to develop effective euthanasia tools and training material for producers has increased significantly. The development and approval of a single step method of euthanasia for all weight classes of swine, such as the “Cash” Dispatch Kit, will provide the industry with a tool that meets the criteria set out in national and international recommendations and regulations.

Just as critical as the effectiveness of the method, is the skill and knowledge level of the stockperson charged with the responsibility euthanasia. Training is vital to ensuring that the method is not only applied correctly, but the ability to assess whether the method
was effective and when a secondary method must be applied. By providing stockpersons
with an understanding of the process of death, what to expect and how to evaluate
sensibility, the effectiveness of the method and in turn the welfare of the animal is
significantly increased.

**Limitations of the thesis projects and future research**

Consideration needs to be given to the limitation that all animals were anesthetized
during the first trial. Other researchers have found that anesthesia may slow the heart rate,
depress respiration and lower blood pressure (Gandomani et al, 2011), which may
account for the difference in the mean time to cessation of heartbeat. Daly (1987) also
questioned the effects that anesthesia had on the parameters that were being monitored.
The comparison of time to last heartbeat between the anesthetized pigs and the farm pigs
supports this theory as all weight classes of anesthetized pigs had longer average time to
last heartbeats than the same weight classes of pigs on farm. This may have an effect on
real life accuracy of some of the data such as cessation of heart beat, cessation of
respiration and bleeding that was collected in the laboratory setting.

The researchers did note that for several of the animals, penetration was at the very
anterior part of the frontal lobe, in some cases just clipping the frontal tip of the brain.
Ideally, the location of penetration would be the parietal section of the brain, since the
brain stem, medulla, thalamus and pons are located below the parietal and occipital areas
of the brain. These are the areas that are targeted for direct damage leading to death
(Gregory, 2004; Reece, 2004). The concussive force would also be more central across
the brain and should create greater hemorrhaging which is critical for effective
euthanasia. These results suggest that the currently recommended target location may be
too low on the forehead of the pig. Due to an unbalanced sample distribution (21
categorized as plank while only 5 were dish shape and 4 were unclear), it was difficult to
assess the influence skull shape had on the location of penetration by the bolt into the
brain. Further research would be warranted on correct targeting for the penetrating
captive bolt gun for not only all weight classes but also on the different skull shape.
EFSA (2004) already recommends that the proper shooting position for mature boars and
sows is 2 - 3 cm higher than slaughter pigs.

Since TBI was only visually assessed on the superficial appearance of abnormalities,
the presence and degree of microscopic lacerations and axonal injury due to the tearing
and shearing caused by the concussive force were not accounted for. Mechanical methods
of euthanasia rely heavily on this microscopic level of brain damage for effectiveness
(EU Scientific Veterinary Committee, 1997) especially to the brainstem, which is the
central control for respiration (Reece, 2004). This fact most likely explains why pigs
consistently died after application of the penetrating captive bolt gun, although visual
TBI to the thalamus, cerebellum, medulla and pons was only present in 1 pig euthanized
with the penetrating bolt. The data supports that direct impact of the bolt with the brain
was not associated with efficacy. Visual evaluation of TBI at a superficial level should
not be considered a reliable indicator of the effectiveness of a mechanical method of
euthanasia such as a penetrating captive bolt. The data though does suggest that
microscopic damage and hemorrhaging is more heavily dependent on concussive force
then direct impact of the bolt on specific regions of the brain direct impact on the brain.
Further research is recommended to assess TBI at a microscopic level and for a
comparison of the importance of damage caused by concussive force, versus damage
caused by direct impact of the bolt into the brain.

The non-penetrating head inflicted significant traumatic brain injury on pigs up to 10 kg. Currently, the non-penetrating is only recommended on pigs up to 5 kg (AASV, 2009), though we found the “Cash” Dispatch Kit non-penetrating head effective on piglets up to 10 kg. Further research is suggested to determine if the non-penetrating head, paired with the appropriate size cartridge could be effectively utilized on pigs up to 20 kg or heavier.

This study was designed to answer a few specific questions about the use of new captive bolt gun technology on swine. These trials have provided some preliminary data to direct future research needs in the use of captive bolt guns and further understanding of the process of death and how sex, weight and skull shape may influence both the effectiveness of the gun and the response from the animal following application. The developers of the “Cash” Dispatch Kit have already utilized this data to modify the gun and the cartridges to meet the needs of the lightest and heaviest weight classes of swine.

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