RESEARCH REPORT
ANIMAL WELFARE

Title: The Adoption of Captive Bolt Technology for On Farm Euthanasia of Swine – **NPB #08-167**
(Concurrent project: #09-196; Original project #06-165, PI: Ms. Jennifer Woods)

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Industry Summary:

In 2007, the National Pork Board organized a conference of equipment manufacturers, producers, veterinarians and safety experts to identify the goals and challenges for developing a euthanasia system specifically designed for commercial pork production facilities. These discussions led British specialist manufacturer Accles & Shelvoke (A&S), and its North American distributor, Bunzl Processor Division, to embark upon developing a system specifically designed for the euthanasia of swine in commercial operations.

The CASH Euthanizer unit is a heavy duty cartridge propelled captive bolt device with interchangeable muzzle assemblies. The unit provides a non-penetrating captive bolt muzzle for piglets, and a variety of penetrating bolt assemblies for pigs ranging from large nursery to adult swine. In addition, the kit includes all necessary equipment for basic cleaning and maintenance of the unit.

Figure 1: Cash Euthanizer Unit

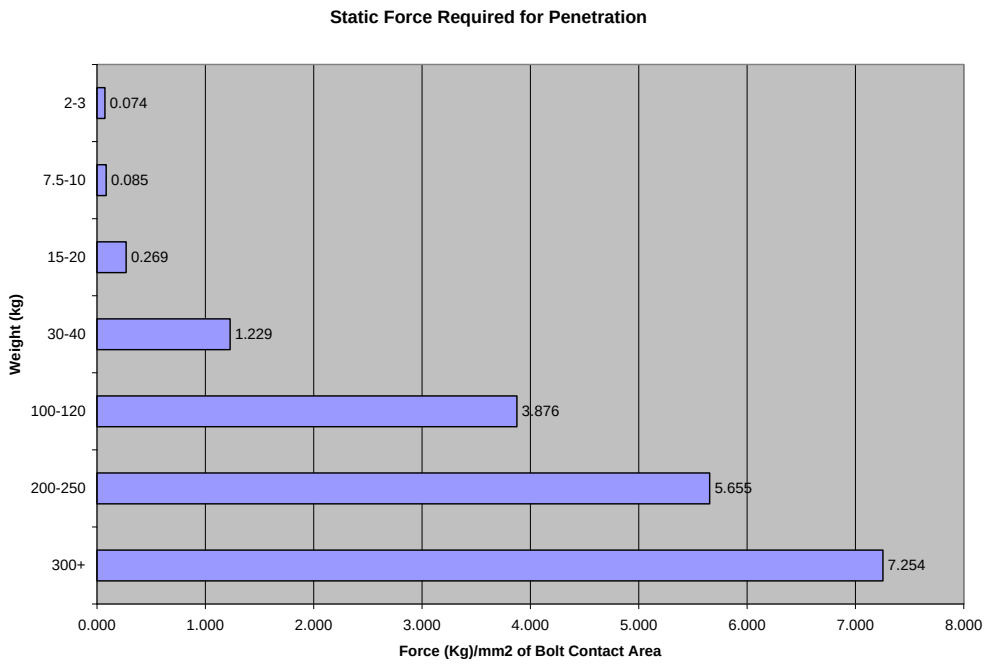
This project was conducted to;

1) To evaluate the anatomical features that determine the effectiveness of captive bolt technology for humane euthanasia of pigs throughout their production life;
2) Determine the traumatic brain injury due to direct damage of the primary regions of the brain of pigs throughout there lifespan from application of the Cash Euthanizer system.

For phase one of the project, the static force required to penetrate the skull plate and sinus cavity was determined for pig heads representing two different skull shapes, three genetic backgrounds, and seven different weight classes.

A Universal Testing Machine was utilized to determine the static force required for penetration of the skull. For the non-penetrating head, the force of penetration was measured when the muzzle face penetrated the skull. For the penetrating bolt, the force of penetration was measured when the bolt penetrated the skull and when the bolt penetrated the sinus cavity. The information gathered on each head included weight, bolt type (non-penetrating head or penetrating bolt), recorded pressure at skull penetration and recorded pressure at sinus penetration

As expected, static force required to penetrate the skull/sinus plate increases significantly as the pig matures, ranging from 0.074 to 7.254 kg/mm^2. This provides the basic information necessary to design a captive bolt system for on-farm euthanasia for the US swine industry. However, to fully evaluate a specific captive bolt system (i.e manufacturer/model) a high-speed penetration test should be conducted utilizing skulls of the target species/size with representative speeds and bolt mass.



For Phase two, the level of brain damage inflicted by the Cash Euthanizer captive bolt gun when applied in recommended locations (National Pork Boards *On-Farm Euthanasia of Swine-Options for the Producer)* was determined by application of the device to cadavers, representing 7 weight classes and both sexes.

Four different muzzles were utilized with the Cash Euthanizer – a non-penetrating head, a short penetrating bolt, a standard length bolt and an extended length bolt. Four different power charges were utilized with the coordinating bolt and weight class. The bolt type and color of the charge were pre-designated based on the manufacturer's recommendations.

The degree of damage to the skull and depth of penetration was documented utilizing dorsal and lateral radiographs. Skulls were dissected to determine the location of penetration and the primary regions of the brain were scored for traumatic brain injury and presence of hemorrhaging.

Dissection of the brains showed that when utilized in a penetrating bolt configuration the placement of the Cash Euthanizer needs to be higher on the forehead of the animal than with traditional penetrating captive bolts. This higher positioning will achieve maximum overall TBI and result in greater impact to regions of the brain necessary to ensure cessation of heart and respiratory function.

The preliminary results demonstrate that captive bolt technology is sufficient to induce significant brain trauma in regions necessary to cause cessation of heart and respiratory function. This support the use of the Cash Euthanizer as an effective single step method for the euthanasia of pigs from 2 kg's up to 200 kgs and recent improvements to the Cash Euthanizer System (addition of a more powerful cartridge) by the manufacturer should ensure a humane euthanasia for even the most mature of swine.

Keywords: Euthanasia, Swine, Captive Bolt

Scientific Abstract

Captive bolt technology is an appropriate method for euthanasia for swine (NPB, 2009), however it is recommended that only captive bolt guns designed for on-farm euthanasia should be used as other products may only stun the pig and may require a secondary step, such as exsanguination or pithing to achieve death. Therefore this project was conducted to;

1) To evaluate the anatomical features that determine the effectiveness of captive bolt technology for humane euthanasia of pigs throughout their production life;
2) Determine the traumatic brain injury due to direct damage to the brain from the application of the Cash Euthanizer system, which is the first commercially available system designed specifically for on-farm euthanasia utilizing captive bolt technology.

The CASH Euthanizer unit is a heavy duty cartridge propelled captive bolt device with interchangeable muzzle assemblies. The unit provides a non-penetrating captive bolt muzzle for piglets, and a variety of penetrating bolt assemblies for pigs ranging from large nursery to adult swine.

For phase one of the project, determination of the force required to penetrate the skull plate and sinus cavity, 42 pig heads representing two different skull shapes and three genetic backgrounds were gathered from four different farms. The heads were allocated into seven different weight classes, equally representing both male and female.

An Instron Universal Testing Machine 4502 was utilized to determine the static force required for penetration of the skull. The non-penetrating head was designated for the 2 -3 kg and 7.5 – 10 kg weight classes, while the remaining five weight classes utilized the penetrating captive bolt rod. Analysis for each head included weight, bolt type (non-penetrating head or penetrating bolt), recorded pressure at skull penetration and recorded pressure at sinus penetration.

As expected, static force required to penetrate the skull/sinus plate increases significantly as the pig matures, ranging from 0.074 to 7.254 kg/mm^2. This provides the basic information necessary to design a captive bolt system for on-farm euthanasia for the US swine industry. However, to fully evaluate a specific captive bolt system (i.e manufacturer/model) a high-speed penetration test should be conducted utilizing skulls of the target species/size with representative speeds and bolt mass.

For Phase two, the level of brain damage inflicted by the Cash Euthanizer was determined by application of the captive bolt device in accordance to manufacturers guidelines, to cadavers representing the seven weight categories of pigs. Application location was in accordance to the targeting recommendations from the *On-Farm Euthanasia of Swine-Options for the Producer (NPB, 2009).*

The degree of damage to the skull and depth of penetration was documented utilizing dorsal and lateral radiographs. Skulls were dissected to determine the location of penetration and the primary regions of the brain (cerebral cortex, thalamus, cerebellum, pons, medulla and sinus areas) were scored for traumatic brain injury and presence of hemorrhaging.

Dissection of the brains showed that when utilized in a penetrating bolt configuration the placement of the Cash Euthanizer needs to be higher on the forehead of the animal than with traditional penetrating captive bolts. This higher

positioning will achieve maximum overall TBI and result in greater impact to regions of the brain necessary to ensure cessation of heart and respiratory function.

The preliminary results demonstrate that captive bolt technology is sufficient to induce significant brain trauma in regions necessary to cause cessation of heart and respiratory function. This supports the use of the Cash Euthanizer as an effective single step method for the euthanasia of pigs from 2 kg's up to 200 kgs and recent improvements to the Cash Euthanizer System (addition of a more powerful cartridge) by the manufacturer should ensure a humane euthanasia for even the most mature of swine.

Introduction:

Euthanasia literally translates to mean a "good death"; however ensuring a "good death" is an issue that the swine industry has struggled with for many years. In past years, situations regarding the inhumane killing of animals have garnered extensive public attention (Choice Connection, Bell Farms, Seaboard Farms, Murphy Brown LLC., etc.), and as a recent court battle in Ohio highlighted, there is significant disagreement and confusion among producers, veterinarians and law enforcement regarding proper methods for euthanasia of pigs. The underlying issue of the industry was pinpointed by case Judge Stuart Miller whom stated "There is no easy, safe or economical way to euthanize a large hog."

In 2007, the National Pork Board organized a conference of equipment manufacturers, producers, veterinarians and safety experts to identify the goals and challenges for developing a euthanasia system specifically designed for commercial pork production facilities.

These discussions led British specialist manufacturer Accles & Shelvoke (A&S), and its North American distributor, Bunzl Processor Division, to embark upon developing a system specifically designed for the euthanasia of swine in commercial operations.
The company's efforts were targeted at producing a euthanasia system that could be used for all ages and sizes of pigs that adhered to basic international standards and followed the criteria outlined by the European Food Safety Authority. The EFSA has previously stated that on-farm euthanasia techniques should:

- Induce unconsciousness and death either simultaneously or sequentially.
- Not rely on a secondary kill step (for example exsanguination) too cause death.

Through extensive design, engineering and testing programs A&S, developed a product that combines the techniques of controlled blunt-force trauma and penetrating captive bolt into a euthanasia system for pigs, ranging from newborn piglets to mature sows and boars.

The CASH Euthanizer unit is a heavy duty cartridge propelled captive bolt device with interchangeable muzzle assemblies. The unit provides a non-penetrating captive bolt muzzle for piglets, and a variety of penetrating bolt assemblies for pigs ranging from large nursery to adult swine. In addition, the kit includes all necessary equipment for basic cleaning and maintenance of the unit.
Figure 1: Cash Euthanizer Unit

Non-Penetrating Captive Bolt (NCPB) Configuration
The goal of controlled blunt force trauma is to provide an exacting force at the precise location necessary to cause massive traumatic brain injury (including to the brainstem) resulting in the immediate loss of consciousness and a humane death.

Blunt force trauma creates a state of immediate unconsciousness and death due to multiple primary effects;

- The impact results in a tissue deforming collision of the brain with the skull.
- Sudden rotational forces lead to shearing strains and stresses within the brain. However to be considered a single step euthanasia technique massive damage (or separation) must result to the brainstem.
- Extensive brain hemorrhage at the point of impact.

NPCB systems must be designed based on the physiological attributes of the target animal (primarily piglets and nursery pigs). For use as a method of on-farm euthanasia, it is imperative that force development and muzzle designs are created that cause a level of traumatic brain injury necessary to result in the loss of consciousness and ensure a humane death, while avoiding extreme force that could cause penetration of the skin, expulsion of brain matter or excessive bleeding.

Force development is determined by the velocity at impact and the muzzle mass, while the critical areas of muzzle designs include;

- Muzzle size (area of impact).
- Muzzle face (flat or convex, curvature of a convex face, etc).
- Edging of the impact face (radiused, perpendicular, etc.).
- Muzzle designs that limit stroke length from penetrating the skull skin.

Table 1: Specifications of the Cash Non Penetrating Muzzle Configuration

Overall Length (mm)		186.25
Stem Length (mm)		154.125
Distance from front face of bolt flange to non-penetrating head face		
Stem Diameter (mm)		11.865
Knocker Head Diameter (mm)		38.3
Knocker Bolt Ass Weight (kg)		286
Kinetic Energy (J)		
	Pink	100
	Yellow	150**

Recommended limited use
Based on Recent Modification and additional powerload

Penetrating Captive Bolt Configurations
Traditional captive bolts are used in slaughter facilities for the stunning of cattle, sheep, goats, and pigs. These create a state of immediate unconsciousness and possibly death due to multiple primary effects;

- Direct trauma due to bolt penetration of the primary regions of the brain
- Sudden rotational forces that lead to shearing strains and stresses which destroy nerve fibres within the brain
- Massive bleeding, bruising and swelling of the tissue in the brain due to stretching effects and shockwave pressures induced by the impact.

Research and industry experience indicate that when properly applied, the brain damage is irreversible and animals will not return to consciousness. The factors that determine if a secondary kill step is required include;

- The proper match of equipment to the age/size of the animal.
- The force developed by the captive bolt unit.
- Proper targeting and positioning of the captive bolt
- Muzzle design of the captive bolt.

In contrast to traditional systems, the CASH Euthanizer utilizes penetrating captive bolt (PCB) technology, which has been specifically developed for on-farm euthanasia. The CASH Euthanizer utilizes a system of captive bolt assemblies (varying in length, mass and edging parameters) and multiple strength cartridges specifically designed based on the physiological parameters (i.e. skull thickness, hardness, brain depth, etc.) of each age/size category of pig. Each kit incorporates a short, standard and extended length penetrating bolt which can be combined with five different cartridges.

Table 2: Specifications of the Cash Penetrating Muzzle Configurations

	Short Bolt	Medium HD	Long HD
Overall Length (mm)	154.5	187.9	206.5
Stem Length (mm)	122.375	155.775	174.375
The distance from the flange face to the poleaxe end of the bolt			
Stem Diameter (mm)	11.865	11.865	11.865
Weight (Kg)	0.19	0.216	0.23
Kinetic Energy (J)			
Pink	112		
Yellow	179**	241	
Blue		295	310
Orange		328	338
Black			433**

Recommended limited use

Objectives:

1) To evaluate the anatomical features that determine the effectiveness of captive bolt technology for humane euthanasia of pigs throughout their production life;
2) Determine the traumatic brain injury due to direct damage of the primary regions of the brain for the seven weight classifications of pigs from application of the Cash Euthanizer system.

Materials and Methods

For phase one of the project, determination of the force required to penetrate the skull plate and sinus cavity, 42 pig heads representing two different skull shapes and three genetic backgrounds were gathered from four different farms. The heads were allocated into seven different weight classes, equally representing both male and female. The pre-determined weight classes were 2-3kg, 7.5-10 kg, 15-20 kg, 30-40 kg, 100-120 kg, 200-250 kg and 300 + kg.

An Instron Universal Testing Machine 4502 (Instron Norwood MA. USA) was utilized at the Iowa State University necropsy laboratory to determine the static force required for penetration of the skull. A non-penetrating captive bolt head and a penetrating captive bolt rod were fitted to the testing machine. The type of bolt applied was pre-determined based on the manufacturers recommendations. The non-penetrating head was designated for the 2 -3 kg and 7.5 – 10 kg weight classes, while the remaining five weight classes utilized the penetrating captive bolt rod.

The skull was retained within a head holder to minimize movement and ensure the target location was perpendicular to the bolt path. The Instron was fitted with a 10kN load cell for the penetrating captive bolts and a 1kN load cell for the non-penetrating captive bolt.

The captive bolt rod was targeted on the heads of the pigs per the current recommendations of the National Pork Board and AASV publication *On-Farm Euthanasia of Swine-Options for the Producer* of one finger width above the eye. For the non-penetrating head, the force of penetration was measured when the head broke through the skull. For the penetrating bolt, the force of penetration was measured when the bolt penetrated the skull and when the bolt penetrated the sinus cavity. The information gathered on each head included weight, bolt type (non-penetrating head or penetrating bolt), recorded pressure at skull penetration and recorded pressure at sinus penetration

For Phase two, the level of brain damage inflicted by the Cash Euthanizer captive bolt gun was determined by application of the captive bolt device to cadavers, representing 7 weight classes and both sexes.

Four different styles of captive bolt gun heads were utilized with the Cash Euthanizer – a non-penetrating head, a short penetrating bolt, a standard length bolt and an extended length bolt. Four different power charges were utilized with the coordinating bolt and weight class. The bolt type and color of the charge were pre-designated based on the manufacturers recommendations. Following are the recommendations for each of the trial weigh classes:

Weight class	Gun Head Style	Charge
2 – 3 kg	non-penetrating head	pink
7.5 – 10 kg	**non-penetrating**	**pink**
15 – 20 kg	short penetrating bolt	pink
30 -40 kg	standard length bolt	yellow
100 – 120 kg	standard penetrating	blue
200 – 250 kg	extended penetrating	orange

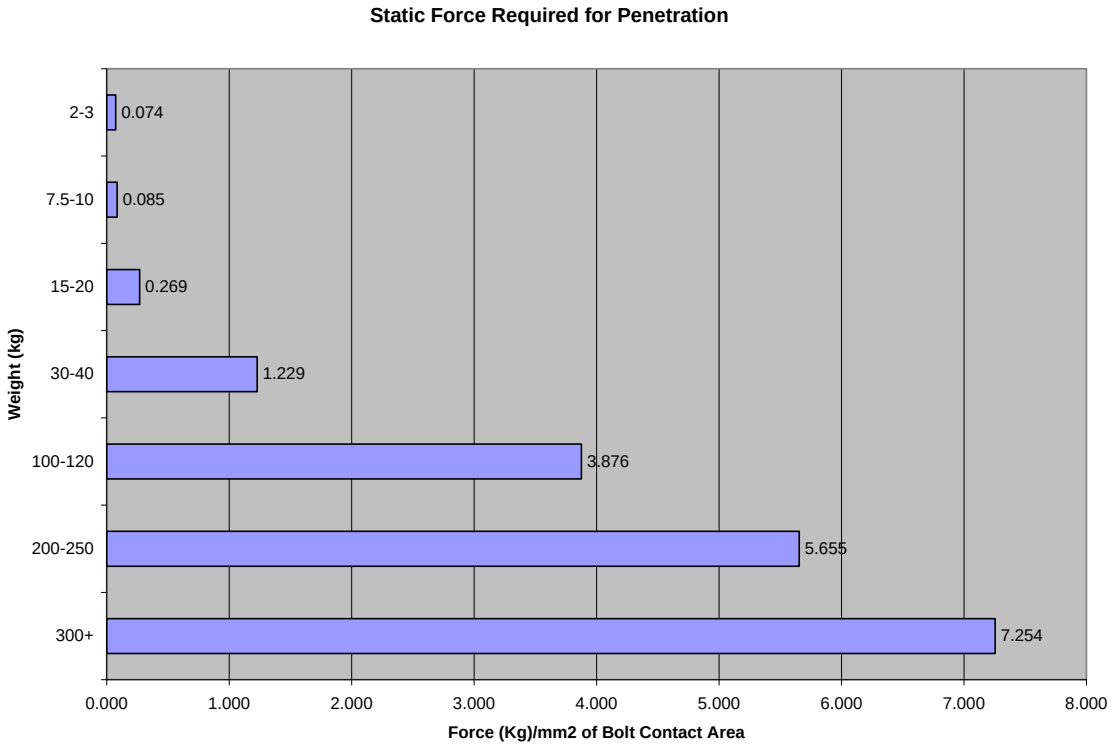
Recent addition by the manufacturer of Black power charges for mature sows and boars to the Cash Euthanizer System

The target location for application of the gun was determined. The location of the shot was based on the National Pork Boards *On-Farm Euthanasia of Swine-Options for the Producer*. For the non-penetrating bolt head the gun was centered on the top frontal part of the skull. For the penetrating captive bolt gun the placement was medial and one inch above the brow. The location was marked by drawing a line across the forehead of the animal using a black felt tip marker. The gun was placed on the location and fired. Heads were removed for the largest weight classes of pig, and the two smaller weight classes were left intact. Dorsal and lateral radiographs were performed with the chin of the pig setting flush to the table. The degree of damage to the skull was documented for the two smallest weight classes, while depth of penetration was documented for the five weight classes euthanized with the penetrating bolt.

Skulls were opened and the location of the shot was documented based on the area of the brain that was penetrated (frontal, parietal, occipital). The brains were scored using a three-point traumatic brain injury (TBI) scale (Millar and Mills 2000) and presence of hemorrhaging. *N* for grossly normal, *1* for some abnormalities and *2* for grossly abnormal/unrecognizable. The areas of the brain scored included the cerebral cortex, thalamus, cerebellum, pons, medulla and sinus. We experimented with dissection of fresh cadavers and skulls that had been fixed in formalin to determine the quality of our TBI evaluation.

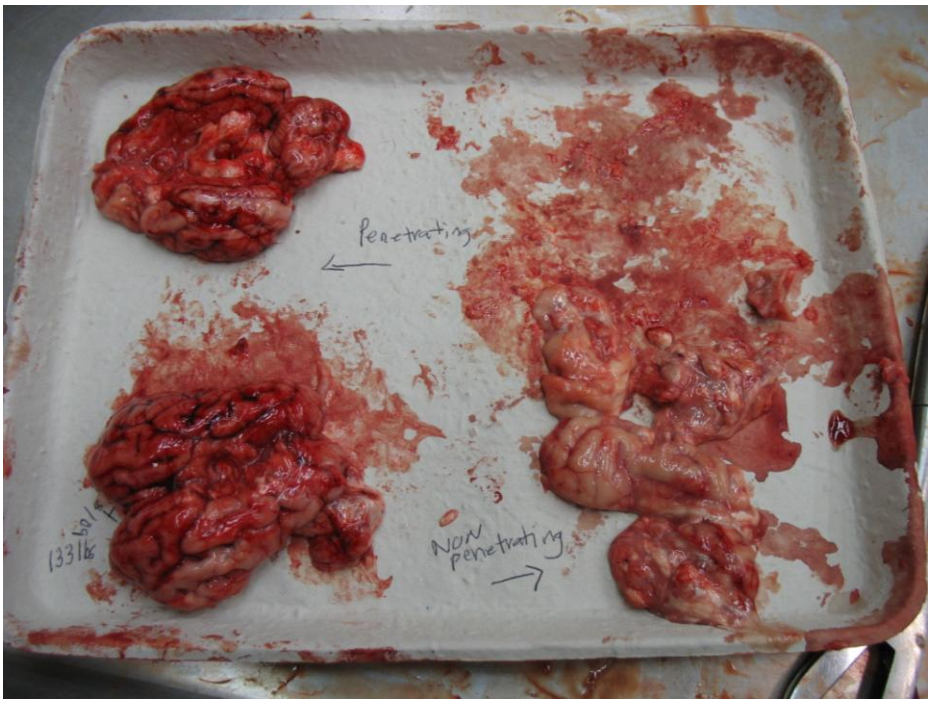
Results

The two main objectives of this project were to determine the effectiveness of the captive bolt technology on all swine weight classes and skull shapes, and to measure the resulting traumatic brain injury. The results from the Instron testing demonstrate the minimum static force requirements for skull penetration of the pig throughout its lifespan. The non penetrating muzzle has a bolt face diameter of 38.3 mm, whereas the penetrating captive bolt has a diameter of 11.865 mm. However as the penetrating captive bolt is tapered to improve penetration capabilities the surface area of impact area is equivalent to total surface area minus surface area of the bore.



The research team conducted an assessment of captive bolt technology for evaluating the anatomical features that impact its effectiveness for on-farm euthanasia and the resultant traumatic brain injury from direct damage to the primary regions of the brain from application of captive bolt technology. Refinement of methodology for port mortem analysis was completed, and applied to the concurrent/linked grant NPB 09-196. Heads are fixed in 2% formalin solution for one week prior to dissection. The frontal and parietal bones are removed as necessary to extract the brain. Gross visual assessment is conducted for trauma associated with brain structures, and sections removed from the brain stem for histology. Bolt penetration is assessed using skull fragment depth.

Our preliminary results suggest that captive bolt technology is sufficient to induce significant brain trauma in regions expected to cause cessation of heart and respiratory function. The photograph below illustrates trauma associated with non-penetrating captive bolt technology applied to a 40 lb swine cadaver (on right) and 133 lb swine cadaver (on left) relative to penetrating captive bolt (note, formalin fixation was not performed on this trial).



Permission was sought and received from National Pork Board (Sherrie Niekamp) to perform the laboratory animal assessment using anesthetized pigs, since this would provide a more realistic model for physiologic and neurologic responses by live, conscious animals. Hence, Phase 2 of this project is merged into NPB 09-196 (PI: Millman), which included Institutional Animal Care and Use Committee approval. Results from this experiment can be found in the August 31, 2010 progress report for NPB #09-196 and should be considered part of the final report for 08-167. [Please see Ms. Sherrie Niekamp or Dr. Suzanne Millman, smillman@iastate.edu, for further explanation].

Discussion

The Instron static force analysis provided the minimum force requirements to penetrate the pig skull throughout its lifespan. However due to the slow speed of travel, the error factors (skull deformation, bone flex, skin slippage, etc.) from evaluating a complex biological system (animal) exacerbated the variability of results. Due to documented slippage and other errors, force measurements greater than one standard deviation from the mean were removed from the data set. To fully evaluate a specific captive bolt system (i.e manufacturer/model) a high-speed penetration test should be conducted utilizing skulls of the target species/size, representative speeds and bolt mass.

The results from cadavers used in this study support the use of the Cash Euthanizer as an effective single step method for the euthanasia of pigs from 2 kg's up to 200 kgs.

Results of the dissection of the brain and skull shape/thickness comparison suggest that the placement of the bolt may be the major factor in failure to achieve a timely death. Bolt placement would affect not just location of penetration but also projection of concussive force through the skull and the brain.

Due to concern for euthanasia effectiveness, the manufacturer has developed a significantly higher-powered cartridge (black) for use with the extended bolt on large mature animals. This cartridge/bolt combination significantly increases concussive force and improves penetration capabilities.

Traditional recommendations for the placement of penetrating captive bolt guns are based on the point of entry for free bullets. Ideally, the projectile will travel into the brain at an angle directing it at the base of the spine or brain stem. Some recommendations state that the gun should be angled slightly (20°), but this will not only lessen the concussive force and depth of penetration, it can also lead to a failure to penetrate the skull at all. Since the captive bolt gun is most effective when held flush to the head, the bolt is unable to achieve the desired angle and maximum TBI when angled.

Dissection of the brains showed that the majority of the animals in all weight classes were hit at the very edge of the cerebral cortex in the frontal part of the brain. This suggests that the placement of the bolt needs to be higher on the forehead of the animal to achieve maximum TBI. By moving the gun higher on the forehead, the peak concussive force should also have more impact on the brain stem area (thalamus, pons, cerebellum) maximizing TBI and hemorrhaging to that area.

The researchers would recommend more extensive research in the exact placement of the bolt on the skull, comparison of skull shape and breed with the thickness of the skull plate for mature pigs. Research should also be extended to determine whether TBI or concussive force has a greater influence on inflicting insensibility and death on an animal through the application of a captive bolt gun.