

# Relationship of captive bolt stunning location with basic tissue measurements and exposed cross-sectional brain area in cadaver heads from market pigs<sup>1</sup>

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**ABSTRACT:** The objective of this study was to contrast the soft tissue thickness, cranial thickness, total tissue thickness, cross-sectional brain area, and bolt–brain contact from the common frontal application of captive bolt euthanasia with the alternative location behind the ear in cadaver swine heads. Twenty-three cadaver heads from pigs that were approximately 136 kg and 6 mo of age were collected from a regional slaughter establishment following CO<sub>2</sub> stunning and assigned to either the FRONTAL ( $n = 11$ ) or the CAUDAL TO PINNA ( $n = 12$ ) application of the captive bolt. The soft tissue thickness was different ( $P < 0.0001$ ) between the 2 applications (FRONTAL:  $8.3 \pm 3.4$  mm; CAUDAL TO PINNA:  $56.5 \pm 3.4$  mm). The cranial thickness was different ( $P < 0.0001$ ) between the applications (FRONTAL:  $23.4 \pm 2.9$  mm; CAUDAL TO PINNA:  $26.5 \pm 2.9$  mm). There was also a difference ( $P < 0.0001$ ) in the total tissue thickness between the 2 applications (FRONTAL:  $31.7 \pm 3.8$  mm; CAUDAL TO PINNA:  $73.4 \pm 3.8$  mm). Cross-sectional area was

calculated from images collected immediately after the heads were cut along the plane of bolt travel by bandsaw and was different ( $P = 0.0028$ ) between the 2 applications (FRONTAL:  $25.2 \pm 1.3$  cm<sup>2</sup>; CAUDAL TO PINNA:  $18.9 \pm 1.3$  cm<sup>2</sup>). Bolt–brain contact was also assessed from the images, and a difference ( $P = 0.0360$ ) between the 2 applications (FRONTAL:  $100 \pm 10.5\%$ ; CAUDAL TO PINNA:  $66.7 \pm 10.5\%$ ) was identified. The results of this study suggest that the FRONTAL application may provide a bolt path with less tissue to travel through when compared with the CAUDAL TO PINNA application for pigs of the approximate age and weight of those in this study. Ultimately, the FRONTAL location may present less risk for the captive bolt euthanasia of swine at market weight at this time. Additional refinement of the CAUDAL TO PINNA procedure and modification to the captive bolt device to penetrate to a suitable depth to ensure brain damage is recommended.

**Key words:** captive bolt, euthanasia, stunning, swine

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## INTRODUCTION

One method of euthanasia approved by the American Veterinary Medical Association (AVMA) for use in swine, specifically sows, boars, and grower-finishers, is penetrating captive bolt (AVMA, 2013, 2016). The common application site of penetrating captive bolt in pigs is a frontal

location. However, 3 possible sites have been identified: frontal, temporal, and behind the ear toward the opposite eye (AVMA, 2013, 2016). In theory, the curious nature of swine could make captive bolt euthanasia by the frontal location more difficult than the location behind the ear. Published data to validate either the temporal or the behind the ear location did not appear to exist at the time of our study. This pilot study was designed to serve as the first step in scientifically validating the behind the ear location.

It is important to consider how an animal dies, as there can be either a substantial amount of pain and suffering at the time of death or a minimal amount of pain and suffering, and these are highly dependent on the method of euthanasia selected (AVMA, 2013; OIE, 2016). The objective of this pilot study was to compare the soft tissue thickness, cranial thickness, total tissue thickness, cross-sectional brain area, and bolt–brain contact from the common frontal application of captive bolt euthanasia with the alternative location behind the ear in cadaver swine heads. Our hypothesis was that the cadaver heads treated with the behind the ear location would display soft tissue thickness, cranial thickness, total tissue thickness, cross-sectional brain area, and bolt–brain contact that was not different than the cadaver heads treated with the frontal application.

## MATERIALS AND METHODS

### *Animal Use Protocol*

It was not necessary to submit an animal use protocol to the University of Wisconsin–River Falls Institutional Animal Care and Use Committee because live animals were not directly manipulated in this study. The pigs from which the heads were obtained were slaughtered at a commercial slaughter establishment under inspection by the United States Department of Agriculture Food Safety and Inspection Service (USDA FSIS) in accordance with the regulations in 9 CFR 313.

### *Description of Cadaver Heads*

Twenty-three heads, skin-on and with intact jowls, were obtained from pigs that were commercially slaughtered at a regional processing facility under federal inspection. The heads were inspected and passed for human consumption. The exact BW and age of each pig were not available; however, the estimated average BW of the pigs was approximately 136 kg and they were approximately 6 mo of age. Each head was removed from the rest of its

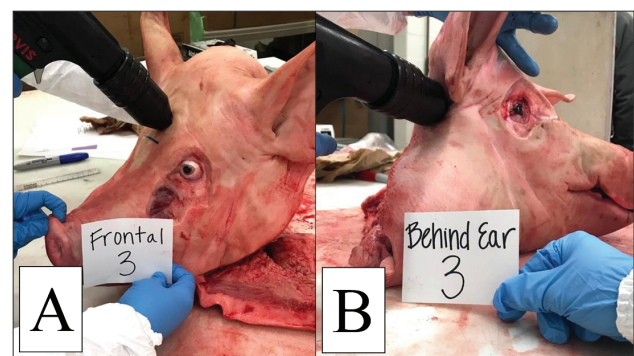
respective carcass with a knife incision between the atlas and axis by plant personnel. All heads were packaged in plastic bags and boxed prior to transport (distance traveled: 180 km) to the University of Wisconsin–River Falls Meat Science Laboratory where the project commenced within approximately 4 h of head collection. During head processing, the average intracranial temperature of a subset of 8 heads was 30.7 °C.

### *Description of Captive Bolt Tool and Placement*

The captive bolt device used in this study was a Jarvis Model PAS–Type P 0.25R Caliber Captive Bolt Pistol (Order #: 4144035, Jarvis Corp., Middletown, CT) equipped with Medium Stunning Rod Nosepiece Assembly (Order #: 3116604, Jarvis Corp.). Jarvis Blue Powder Cartridges–0.25R Caliber, 3GR (Order #: 1176018, Jarvis Corp.) were utilized for all captive bolt applications in this study. Two captive bolt placement treatments (Figure 1) were applied in this study: **FRONTAL**—shot placed 2.54 cm superior to a line drawn across the top of the eyes at midline (Woods et al., 2010) or **CAUDAL TO PINNA**—shot placed directly caudal to the pinna of the right ear on the same plane as the eyes and targeting the middle of the opposite eye (AVMA, 2013, 2016).

### *Postapplication Head Processing*

Following the application of the shot location treatment, each head was cut along the bolt path with a meat band saw. For **FRONTAL** heads, an approximately 8 cm portion of the snout was removed with a single band saw cut that was perpendicular to the midline. This cut was made to prevent damage to the band saw blade from contact with the



**Figure 1.** Placement of captive bolt device for placement treatments. (A) **FRONTAL**—medial bolt entry approximately 2.54 cm superior to a line across the top of both eyes and perpendicular with the external surface of the head; (B) **CAUDAL TO PINNA**—bolt entry directly caudal to the right pinna with aim toward the left eye on a plane that included both eyes.

enamel of the incisors. Following each cut, digital images were collected from both the right and left sides of each exposed intracranial surface for the FRONTAL heads and the posterior and anterior sides for CAUDAL TO PINNA heads.

### Tissue and Cranial Measurements

Measurements of soft tissue thickness, cranial thickness, and total soft and cranial tissue thickness were collected following the splitting of each head. Soft tissue thickness referred to the tissue from the application site to the exterior surface of the cranium. Cranial thickness referred to the thickness from the exterior surface of the cranium to the interior surface of the cranium along the bolt path. Total thickness referred to the total soft tissue and cranial thickness from the site of application to the interior surface of the cranium along the bolt path. Soft tissue thickness, cranial thickness, and total thickness were measured and recorded in mm. Two measurements—one on each side of the bolt travel path—were recorded for cranial thickness and total tissue thickness on each cadaver head, as visually noticeable differences were recognized in the cranial thickness on each side of the bolt path. The 2 values were averaged for each measurement prior to statistical analysis. Cross-sectional brain area (cm<sup>2</sup>) was determined from the images that were collected during head processing. An online irregular area calculator application (SketchandCalc, iCalc, Inc., Palm Coast, FL) was utilized to calculate the cross-sectional surface area of the exposed brain within the plane of bolt travel. Bolt–brain contact was also determined from the images on a yes/no basis where yes meant the brain was contacted by the bolt and no meant the brain was not contacted by the bolt.

### Statistical Analyses

All continuous data for captive bolt application treatment (FRONTAL, CAUDAL TO PINNA) effects were analyzed using models constructed within the MIXED procedure of SAS (Statistical Analysis System Institute, Inc., Cary, NC) in an unpaired-comparison design with Kenward–Roger denominator degrees of freedom designated within each model and mean separation performed with the Tukey's test designation. Categorical data for treatment effects were analyzed using a generalized linear mixed model constructed in the GLIMMIX procedure of SAS (Statistical Analysis System Institute, Inc.). Categorical data in this study were binomially distributed (yes, no) and converted to binary (1, 0) format prior to analysis. For all analyses, the experimental unit was individual head. Significant differences in treatment effects were recognized at  $\alpha \leq 0.05$ .

## RESULTS AND DISCUSSION

Tissue measurements collected in this study can be observed in Table 1. All measurements were significantly ( $P < 0.05$ ) different between the FRONTAL and CAUDAL TO PINNA treatments. The soft tissue thickness was greater ( $P < 0.0001$ ) in CAUDAL TO PINNA heads ( $56.5 \pm 3.4$  mm) than FRONTAL heads ( $8.3 \pm 3.4$  mm). It is important to note that the soft tissue located directly caudal to the pinnae of all heads was very soft and malleable. As a result, it is possible that the soft tissue thickness may be less in vivo because the intact skin would assist in maintaining soft tissue depth; however, the magnitude of soft tissue depth difference between the 2 treatments is suggestive of a true difference in soft tissue thickness irrespective of the

**Table 1.** Effects of location on tissue parameters and cross-sectional brain area of cadaver heads from market weight hogs assigned to 2 shot location treatments<sup>1</sup> and sectioned by band saw following the plane of bolt entry ( $N = 23$ )

Dependent variable	Captive bolt placement location			P-value
	FRONTAL ( $n = 11$ )	CAUDAL TO PINNA ( $n = 12$ )	Pooled SE	
Soft tissue thickness, mm	8.3	56.5	3.4	<0.0001
Cranial thickness, mm	23.4	26.5	2.9	<0.0001
Total tissue thickness, mm	31.7	73.4	3.8	<0.0001
Cross-sectional brain area, cm <sup>2</sup>	25.2	18.9	1.3	0.0028
Bolt–brain contact <sup>2</sup> , count/%	11/100	8/66.7	10.5	0.0360

<sup>1</sup>Treatments: FRONTAL—medial bolt entry approximately 2.54 cm superior to a line across the top of both eyes and perpendicular with the external surface of the head; CAUDAL TO PINNA—bolt entry directly caudal to the right pinna with aim toward the left eye on a plane that included both eyes.

<sup>2</sup>Bolt–brain contact: images of heads sectioned by band saw within the plane of bolt entry were assessed for occurrence of bolt contact with brain tissue.

fact that the heads were not intact with the bodies of the pigs.

Cranial thickness was also less ( $P < 0.0001$ ) in **FRONTAL** heads ( $23.4 \pm 2.9$  mm) than **CAUDAL TO PINNA** heads ( $26.5 \pm 2.9$  mm). Total tissue thickness, which was composed of the combination of soft tissue and cranium thickness, was greatest ( $P < 0.0001$ ) for the **CAUDAL TO PINNA** heads ( $73.4 \pm 3.8$  mm) compared with the **FRONTAL** heads ( $31.7 \pm 3.8$  mm). The area of the exposed brain surface within the plane of bolt travel also differed between treatments ( $P = 0.0028$ ) as the **FRONTAL** heads displayed greater exposed surface area ( $25.2 \pm 1.3$  cm<sup>2</sup>) than the **CAUDAL TO PINNA** heads ( $18.9 \pm 1.3$  cm<sup>2</sup>). Although all brains were contacted by the captive bolt in the **FRONTAL** treatment, the bolt contacted  $66.7 \pm 10.5\%$  (8 heads) of brains in the **CAUDAL TO PINNA** treatment ( $P = 0.036$ ). Review of images that we captured immediately before cartridge detonation with the captive bolt device in place revealed variation in the angle of elevation between heads. The captive bolt device operator reported that it was difficult to align the barrel of the device to ensure bolt travel within the same plane as the eyes while working in a standing position. The position that the device operator maintained during the **CAUDAL TO PINNA** treatment application was similar to the vantage point that a device operator would assume during field euthanasia of a live pig. It is important for refinement of training and ergonomic profile of the device to be considered if the **CAUDAL TO PINNA** location is selected for euthanasia of swine.

In an evaluation of the efficacy of a captive bolt device that was nearly identical to the model used in our study, Woods (2012) concluded that the device was effective and reliable for the euthanasia of pigs as heavy as 200 kg. However, its use in pigs that weighed greater than 200 kg was not consistently effective and reliable (Woods, 2012). The European Food Safety Authority (EFSA) (2004) also identified that the efficacy of captive bolt stunning is dependent on accurate shot placement, but may be ineffective in some mature sows and boars. Woods (2012) specifically investigated the efficacy of captive bolt application to the frontal location of the head. Chevillon et al. (2004) reported that the captive bolt pistol is the recommended euthanasia method for piglets heavier than 8 kg, growing pigs, and breeding animals; provided the efficacy, feasibility, and cost compared with other euthanasia methods. Physical methods of euthanasia, including captive bolt, present a problem as a pig ages.

The skull continues to grow and cranial thickness increases relative to brain size (Woods et al., 2010). This may result in greater difficulty in placing accurate and effective captive bolt shots. Pigs are described as one of the most difficult livestock species to stun with captive bolt equipment (Humane Slaughter Association, 2013), and thus a difficult livestock species to effectively euthanize with captive bolt devices. Furthermore, various breeds may have differing skull shapes which may change as a pig ages (Woods et al., 2010). Additionally, the target area is relatively small, and the brain is located deep within the head (Humane Slaughter Association, 2013).

Our results suggest that **FRONTAL** application may provide a bolt path with less tissue to travel through than the **CAUDAL TO PINNA** application for pigs that are approximately 6 mo of age. It must be noted that the cadaver heads utilized in this study did not have the thickened and developed sinus cavity typical of older or more mature pigs (NPB, 2008). Both the National Pork Board (NPB) and AVMA describe the process of selecting the best anatomical location for captive bolt euthanasia in mature sows and boars as difficult due to the nature of varying skull shapes and the thickened sinus cavity (NPB, 2008; AVMA, 2013). Additionally, Woods et al. (2010) noted that mature sows have a large sinus cavity located directly in front of the brain and boars develop a ridge down the front of their skull with maturity; both of these factors contribute to the difficulties in frontal captive bolt stunning described by the NPB and the AVMA (Woods et al., 2010).

## IMPLICATIONS

The reliability of a selected euthanasia method is essential to maintaining the best possible state of welfare for the animal until consciousness is lost. The behind the ear location, identified as **CAUDAL TO PINNA** position in this study for euthanasia of swine via captive bolt has been approved with little to no published scientific validation. As such, this study was intended to serve as a first step in the scientific refinement and validation of this approach. Of the 2 locations for captive bolt euthanasia that were analyzed in this study, the **FRONTAL** position appears to be a more reliable location at this time. The reliability of the **FRONTAL** position over the **CAUDAL TO PINNA** position is indicated by greater incidence of bolt–brain contact noted in the cadaver heads treated with the **FRONTAL** application of the captive bolt. Additionally, the **CAUDAL TO PINNA** position requires an increased level of

accuracy with both the aim for the bolt path and the angle at which the device must be placed against the pig. Thus, further studies into the angle and position of application as related to the CAUDAL TO PINNA position for the euthanasia of pigs with penetrating captive bolt are recommended. This study identified that refinement of the CAUDAL TO PINNA position is necessary to ensure its reliability in practice. The FRONTAL location may present less risk for the captive bolt euthanasia of swine at market weight at this time.

### LITERATURE CITED

- AVMA. 2013. AVMA guidelines for the euthanasia of animals: 2013 edition. <https://www.avma.org/KB/Policies/Documents/euthanasia.pdf> (Accessed 5 March 2019).
- AVMA. 2016. AVMA guidelines for the humane slaughter of animals: 2016 edition. <https://www.avma.org/KB/Resources/Reference/AnimalWelfare/Documents/Humane-Slaughter-Guidelines.pdf> (Accessed 5 March 2019).
- Chevillon, P., C. Mircovich, S. Dubroca, and J. Fleho. 2004. Comparison of different pig euthanasia methods available to the farmers. In: Proc. Int. Soc. Anim. Hyg., St-Malo, France. p. 45–46.
- EFSA. 2004. Opinion of the scientific panel on animal health and welfare on a request from the commission related to welfare aspects of the main systems of stunning and killing the main commercial species of animals. EFSA J. 45:1–29. doi:10.2903/j.efsa.2004.45
- Humane Slaughter Association. 2013. Captive bolt stunning of livestock. <https://www.hsa.org.uk/downloads/publications/captive-bolt-stunning-of-livestock-updated-logo-2016.pdf> (Accessed 5 March 2019).
- NPB. 2008. On-farm euthanasia of swine: recommendations for the producer. Tech. Bull. No. 04259-01/09. National Pork Board, Des Moines, IA.
- OIE. 2016. Terrestrial animal health code: killing of animals for disease control purposes. [http://www.oie.int/fileadmin/Home/eng/Health\\_standards/tahc/current/chapitre\\_aw\\_killing.pdf](http://www.oie.int/fileadmin/Home/eng/Health_standards/tahc/current/chapitre_aw_killing.pdf) (Accessed 5 March 2019).
- Woods, J. 2012. Analysis of the use of the “CASH” Dispatch Kit captive bolt gun as a single stage euthanasia process for pigs. MS Thesis. Iowa State University, Ames.
- Woods, J., J. K. Shearer, and J. Hill. 2010. Recommended on-farm euthanasia practices. In: T. Grandin, editor, Improving animal welfare: a practical approach. CAB International, Oxfordshire, UK. p. 195–201.