Head-only followed by cardiac arrest electrical stunning is an effective alternative to head-only electrical stunning in pigs

K. D. Vogel,*2 G. Badtram,† J. R. Claus,‡ T. Grandin,* S. Turpin,‡ R. E. Weyker,‡ and E. Voogd§

*Department of Animal Science, Colorado State University, Fort Collins 80523; †Wisconsin Department of Agriculture, Trade, and Consumer Protection, Division of Food Safety, Madison 53708; ‡Department of Animal Sciences, University of Wisconsin, Madison 53706; and §Voogd Consulting Inc., West Chicago, IL 60185

ABSTRACT: Many small slaughter facilities use head-only electrical stunning to render swine unconscious and insensible to pain before slaughter. Head-only electrical stunning is a reversible procedure that is optimally effective for approximately 15 s after stun completion. In many small North American slaughter plants, the authors have observed hoist speeds that are too slow to achieve a short enough stun-to-bleed interval to maintain insensibility through exsanguination. Unlike many European plants, there is no separate high-speed hoist for pigs and exsanguination on the floor is not condoned. As a result, a 2-stage stunning method was proposed where head-only stunning for 3 s was immediately followed by application of the same stunning wand to the cardiac region of the animal for 3 s while lying in lateral recumbancy. A paired-comparison study was conducted on 89 pigs in a small slaughter facility to compare the head-only method applied for 6 s with the head/heart method. The objective was to evaluate signs of return to sensibility, stun-to-bleed time, blood lactate concentration, muscle pH, drip loss, and fresh meat color to validate the head/heart electrical stunning method for small slaughter plants. Incidence of corneal reflex was not different (P > 0.05) between head/heart (93.8%) and head only (85%) stunning. Nose twitching was more common (P < 0.05) in head only (26.5%) than head/heart (5%) stunning. Head/heart stunning eliminated rhythmic breathing, natural blinking, eye tracking to moving objects, and righting reflex, which were all observed in head-only stunned pigs. Eye tracking to moving objects was observed in 40.8% of head-only stunned pigs. Blood lactate was not different (P > 0.05) between stunning methods (head only: 8.8 ± 0.7 mmol/L, head/heart: 7.8 ± 0.7 mmol/L). Stun-to-bleed time did not differ (P > 0.05; head only: 32 ± 1 s, head/heart: 33 ± 1 s). Mean time to loss of heartbeat with the head-only method was 121 ± 5 s. No heartbeat was observed with the head/heart method. Longissimus thoracis pH, color, and drip loss were not different (P > 0.05) between stunning methods. This study determined that the head/heart electrical stunning method reduces the incidence of signs of return to sensibility without significant effects on meat quality, plant operation speed, or blood lactate concentration. In addition, the head/heart method requires no capital investment for plants that are currently using the head-only method.

Key words: cardiac arrest, insensibility, slaughter, stunning, swine, welfare

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INTRODUCTION

Head-only electrical stunning is a reversible stunning method used in many small commercial slaughter plants. When head-only electrical stunning is used, exsanguination should occur before 15 s has elapsed after the end of the stun (Wotton and Gregory, 1986; Anil, 1991). Effective and complete bleeding is very important to ensure rapid death and meat quality in slaughtered livestock (Anil et al., 1997, 2000; Grandin, 2001). The 15-s interval can be met with rapid shackle- and hoisting or bleeding on a platform or the floor.

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2Corresponding author: kurt.vogel@uwrf.edu

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before shackling and hoisting. In small North American slaughter plants, the authors have observed hoist speeds that may be too slow to achieve a short enough stun-to-bleed interval. In addition, bleeding on the floor can be awkward and difficult and may result in poor bleeding or employee injury. Most North American slaughter inspection personnel do not condone bleeding on the floor because it presents an additional vector for microbial carcass contamination.

An extension of the insensible period between stunning and bleeding would be useful in ensuring the welfare of electrically stunned slaughter pigs. Some small slaughter plants have begun to use a 2-stage stun where head-only stunning is immediately followed by application of the stunning wand to the chest of the pig near the heart (head/heart method). The head/heart method may improve pig welfare by killing the stunned animal before it can recover consciousness.

The hypothesis of this study was that pigs stunned using the head/heart method would display fewer signs of sensibility, earlier loss of detectable heartbeat, and meat quality that was not different than head-only stunned pigs. The objective of this study was to evaluate signs of return to sensibility, stun-to-bleed time, blood lactate concentration, muscle pH, drip loss, and fresh meat color to validate the head/heart electrical stunning method for small slaughter establishments.

**MATERIALS AND METHODS**

All procedures involving live animals in this study were approved by the Animal Care and Use Committees at both collaborating universities because one purpose of this study was to validate modifications of commonly used industry procedures that would improve pig welfare under commercial conditions. The Colorado State University Animal Care and Use Committee approval number was 08-341A-01. The University of Wisconsin protocol number was A1377.

**Description of Animals and Stunning Method**

Eighty-nine pigs (market barrows and gilts, various breeds, mean HCW = 88.5 ± 10.4 kg) from 18 farms in southwestern Wisconsin were slaughtered on 3 d over 3 wk in a Wisconsin state-inspected meat processing facility. All pigs arrived at the plant on the morning of each slaughter day. All farms of origin were located within 172 km of the slaughter facility. The farms of origin varied with regard to management practices, feeding regimens, and outdoor access. At the time of slaughter, groups of 2 to 8 pigs, with an average group size of 5 pigs, were moved 8 m from lairage to a stunning pen on the slaughter floor of the processing facility. Electric prods were used to move approximately 16 to 20% of the pigs. Before stunning, each pig was dampened with a light mist of water, such that the pig was not dripping. All pigs were stunned with a commonly used fixed-volt-

age electric hog stunner (model ES, Best and Donovan Corp., Cincinnati, OH) equipped with model 9600100 stunning wand assembly. Stunner output during application to a pig was 313 V, and mean current was 2.3 A at 60 cycles/s. Two stunning treatments (head, the head-only method, 6 s application of stunning wand in the hollow behind the ears; and head/heart, the head/ heart method, 3 s application of stunning wand behind the ears followed by 3 s application of stunning wand to the ventral region of the ribcage directly caudal to the junction of the humerus and scapula while the stunned pig was in lateral recumbency) were applied in an alternating manner in the slaughter order such that every other pig received the same treatment. Each pig was stunned while standing in the holding pen. No restraint device was used. Upon conclusion, all stuns immediately resulted in tonic and clonic convulsive activity indicative of epileptiform brain activity and insensibility (Blackmore and Newhook, 1982; Anil, 1991; Anil et al., 1997).

**Stun to Bleed Time, Loss of Detectable Heartbeat, and Blood Lactate Determination**

Immediately after stun completion, a digital stopwatch was started to measure stun-to-bleed time and time to loss of detectable heartbeat. Loss of detectable heartbeat by stethoscope was performed, immediately after commencement of exsanguination, by a veterinarian that was blinded to the applied stunning treatment. Immediately after commencement of exsanguination, an exsanguination blood sample was captured in a 7-mL blood collection tube with sodium fluoride potassium oxalate additive (Becton, Dickinson and Company, Franklin Lakes, NJ) for blood lactate measurement at the end of the slaughter shift. Blood lactate was measured with a hand-held lactate analyzer (Lactate Scout, EKF Diagnostic GmbH, Magdeburg, Germany) as described by Edwards (2009).

**Assessment of Insensibility**

Signs of return to sensibility were monitored beginning immediately after shackling, hoisting, and the commencement of exsanguination, which was approximately 30 s after the conclusion of the stun and within 2 s of the beginning of bleeding. Monitoring continued until slaughter procedures began approximately 4 min after the commencement of bleeding. Clonic spasms were still present at the commencement of exsanguination, which is indicative of insensibility (Anil, 1991). Monitoring continued until pigs were moved to a cradle for skinning. The following signs of return to sensibility were monitored: corneal reflex (eye blink from touch), dazzle response (eye blink from application of a bright light to the eye), nose twitching without stimulus, rhythmic breathing, natural blinking, eye tracking to a moving object, and righting reflex. Signs of sen-
sibility were monitored by a trained observer. All pigs in the study were monitored by the same observer to eliminate interobserver variation.

Corneal reflex was evaluated by physical touch of the cornea of the eye with the blunt end of an LED emitting diode (LED) penlight (Streamlight 65018, Eagleville, PA). Any blink or twitch of the eyelid associated with this test was considered a corneal reflex. Dazzle response was measured by shining an LED penlight (light output: 10 lm, Streamlight 65018) directly into the eye of the stunned pig at a maximum distance of 15.2 cm. To be considered a reaction, the eyelid of the pig needed to close or partially close when the light was applied, then open or partially open when the light was removed. Nose twitching without stimulus was defined as movement of the snout without a touch stimulus. Rhythmic breathing was recorded when 2 or more sequences of expansion and contraction of the rib cage were observed. Rhythmic breathing was detected visually and confirmed by stethoscope during heartbeat monitoring. Natural blinking was defined as the full closure and reopening of the eyelids as observed in sensible pigs in lairage with no stimulus applied to their eyes by an observer. Eye tracking to a moving object was recorded if the eye moved to focus on an object passed in front of the eye. The penlight that was used for dazzle response and corneal reflex was moved side to side perpendicular to the line of sight of the pig at a distance of 15.2 cm. The penlight was turned off for this test. Eye tracking was only recorded if the eye followed the object (i.e., rolling of the eyes was not a response). The righting reflex response is arching of the back in an attempt to regain a lateral position with the floor. Nose twitch, rhythmic breathing, natural blinking, eye tracking, and righting reflex were considered indicators of sensibility, and animals showing these signs were immediately restunned with a handheld captive bolt stunner.

**Fresh Meat Color and pH Assessment**

Forty-eight hours after slaughter, carcasses were butchered for further processing by the plant. Meat color and pH was assessed at this time. Color was determined using a colorimeter (model CR300, 8 mm aperture, Minolta Camera Co. Ltd., Osaka, Japan) standardized against a white (No. 20933026 CIE L* 97.91, a* −0.70, b* +2.44) calibration plate. The colorimeter was used to determine CIE color space (L* a* b*) values on the cut surface of the gluteus medius in triplicate and gluteus accessorius in duplicate on the ham side of the ham/loin junction of the left side of each carcass. The cut surface was allowed to bloom for 30 min before color was measured. For each carcass, the replicate color space values for each muscle were averaged to yield a single set of values for each muscle for statistical analysis. Longissimus thoracis pH was determined in duplicate 48 h postmortem with a pH meter (Accumet AR 50, Fischer Scientific, Pittsburgh, PA) equipped with a glass-encased pH probe (Orion 910600, Thermo Electron Corp., Beverly, MA) using a 10-g sample of the pork chop used for color assessment homogenized in 90 mL of distilled, deionized water.

**Drip Loss Determination**

Drip loss was determined using methods similar to those outlined by Honikel and Hamm (1995). After color analysis, a 5 cm × 5 cm × 2.5 cm cube was cut from the center of each sample pork chop. Each cube was weighed and suspended in an air-tight container by a fishing hook and fishing line attached to the lid of the container such that no surface within the container made contact with the suspended sample. All containers were placed in a walk-in cooler and maintained at 2 to 4°C until reweighing 48 h later.

**Statistical Analysis**

Continuous data were analyzed in 2-paired comparison designs. The first analysis compared the 2 stunning treatments (head, head/heart). The second analysis compared the group means of pigs from the 18 farms in the study. Individual animal was the experimental unit for the analysis of treatment and farm effects. In both designs, all main effects and interactions were included in the models using the GLIMMIX procedure (SAS Inst. Inc., Cary, NC) for generalized linear mixed models with Kenward-Roger denominator degrees of freedom designated within the model (SAS Inst. Inc.). Interaction effects that were declared not significant at α > 0.05 were removed from the model in a stepwise manner until only significant interactions and all main effects remained in the model. Significant differences in treatment effects and farm effects on continuous data were realized at α < 0.05.

Categorical data for treatment effects on signs of return to sensibility were analyzed using 2-sided Fisher’s exact tests in the frequency procedure of SAS. Categorical data in this study were binomially distributed (yes, no). Significant differences in frequency of incidence of signs of return to sensibility were realized at α < 0.05.

**RESULTS AND DISCUSSION**

The head/heart method eliminated rhythmic breathing, natural blinking, eye tracking to a moving object, and righting reflex in the pigs observed in this study (Table 1). The head-only method pigs showed increased (P < 0.05) incidence of nose twitch in contrast to head/heart pigs. No difference (P > 0.05) was observed in
the incidence of corneal reflex or dazzle response between stunning treatments. However, the occurrence of the corneal reflex and dazzle response were common regardless of stun treatment. McKinstry and Anil (2004) found that corneal reflexes returned in head-only stunned pigs after 37 ± 12 s had elapsed if exsanguination was not performed. Other authors have reported similar times to the return of corneal reflexes in electrically stunned calves, sheep, and pigs (Anil, 1991; Anil and McKinstry, 1992; McKinstry and Anil, 2004). The time between stunning and the beginning of bleeding in our study was 32 to 33 s, which may allow adequate time for the corneal reflex to redevelop before the commencement of exsanguination.

The presence of a corneal reflex in livestock that have been electrically stunned in a manner that induces epileptiform activity and cardiac failure may not be an indicator of sensibility on the part of the stunned animal. Blackmore and Newhook (1982) recorded an immediate decline in blood pressure after head-to-back electrical stunning to undetectable levels within 35 s in sheep. The authors have observed that corneal reflexes can be evoked from animals that show no other signs of insensibility. In our study, pigs that were stunned with the head/heart method commonly displayed corneal reflexes after the commencement of exsanguination. Corneal reflexes have been observed beginning 10 to 20 s after head-to-back stunning and subsequent cardiac failure in sheep and calves (Blackmore and Newhook, 1982). Blackmore and Petersen (1981) monitored corneal reflexes in 35 calves stunned using a head-to-back stunning wand and 2 A of current for 5 s. In the study, 60% of calves displayed corneal reflexes for a mean duration of 59 s, although none of the calves displayed a detectable heartbeat by stethoscope. A maximum of 225 s elapsed before loss of corneal reflexes occurred in one calf in the study. The elimination of rhythmic breathing and detectable heart beat in head/heart pigs in our study does not support the likelihood of a return to sensibility. In sheep and calves that were electrically stunned using a head-to-back method, insensibility was permanent in all animals that did not have a detectable heartbeat (Blackmore and Newhook, 1982). There is a need to do further research on these residual brain stem reflexes.

In a previous study of 6 large commercial pork slaughter facilities, the fourth author did not observe corneal reflexes in electrically stunned pigs (Grandin, 2001; Grandin, unpublished data). However, the author evaluated corneal reflexes approximately 60 s after stunning, which was 15 to 30 s after the commencement of exsanguination. The blood loss sustained before the observer tested corneal reflexes may have been sufficient to abolish brain stem activity, which is responsible for corneal reflexes. We evaluated the corneal reflex beginning approximately 2 s after the commencement of exsanguination. It is possible that our observations fell within a period of recurrence for the corneal reflex before it was abolished by brainstem hypoxia as a result of cardiac arrest or blood loss. Further research is necessary to identify the cause and duration of corneal reflex recurrence after electrical stunning when cardiac arrest has occurred. Other authors have identified the application of a painful stimulus to the nose of stunned pigs as a reliable test of sensibility (Anil, 1991; Anil et al., 1997; Grandin, 2009). Additional research regarding this method is also warranted.

No difference (P > 0.05) was observed in stun-to-bleed time between head and head/heart (Table 2). Head pigs maintained a detectable heartbeat for more time (P < 0.01) than head/heart pigs. No head/heart pigs maintained a detectable heartbeat beyond the time when heartbeat monitoring began. Blackmore and Newhook (1982) also observed immediate loss of

### Table 1. Stun treatment effects on incidence of signs of return to sensibility in electrically stunned pigs (n = 89)

<table>
<thead>
<tr>
<th>Dependent variable, %</th>
<th>Head</th>
<th>Head/heart</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corneal reflex</td>
<td>93.8</td>
<td>85.0</td>
<td>0.29</td>
</tr>
<tr>
<td>Dazzle response</td>
<td>38.8</td>
<td>42.5</td>
<td>0.83</td>
</tr>
<tr>
<td>Nose twitch</td>
<td>26.5</td>
<td>5.0</td>
<td>0.01</td>
</tr>
<tr>
<td>Rhythmic breathing</td>
<td>12.2</td>
<td>0.0</td>
<td>0.03</td>
</tr>
<tr>
<td>Natural blinking</td>
<td>40.8</td>
<td>0.0</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Eye tracking to moving object</td>
<td>32.7</td>
<td>0.0</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Righting reflex</td>
<td>14.3</td>
<td>0.0</td>
<td>0.02</td>
</tr>
</tbody>
</table>

a,bPercentages under stun treatment within a row with unlike superscripts are different (P < 0.05).

1Signs of return to sensibility were monitored continuously by a trained observer beginning approximately 2 s after the commencement of exsanguination and ending approximately 4 min later. Corneal reflex: eye blink in response to physical contact of the cornea with the end of a penlight; dazzle response: eyelid movement in response to a penlight beam applied to the eye at 15.2 cm distance; nose twitch: twitching of the nose without provocation; rhythmic breathing: more than one successive expansion/contraction of the rib cage; natural blinking: closure and reopening of the eyelid without provocation; eye tracking to moving object: eye movement following the movement of a penlight held perpendicular to the line of sight at 15.24 cm distance and moved from side to side; righting reflex: arching of the back in an attempt to regain a lateral position with the floor.

2Stun treatments: head: 6-s electrical stun applied behind ears; head/heart: 3-s electrical stun applied behind ears followed by 3-s electrical stun applied directly caudal to the forelimb and dorsal to the sternum.
No difference \( (P > 0.05) \) was observed in blood lactate concentration between stunning treatments. A farm effect \( (P < 0.05) \) was observed with regard to blood lactate concentration. The variation in muscle fiber type and diameter between breeds appears to have a major influence on lactate production (Reiner et al., 2002). Handling stress and short transport time have also been linked to increased blood lactate concentration (Hambrecht et al., 2004; Apple et al., 2005; Allison et al., 2006). In summary, multiple factors are responsible for preslaughter blood lactate concentration differences, but it is impossible to identify the factors responsible for the effects observed in this study.

Petechial hemorrhages were not observed in the longissimus thoracis samples collected in this study. The fourth author has been able to reduce petechial hemorrhages in pigs by stopping double stunning. In our study, the stunner operator was highly skilled, and double stunning was not observed. In addition, the head-to-back stunning method studied by Wotton et al. (1992) includes the longissimus thoracis in the electrical circuit, which causes violent muscle contraction in the muscle, resulting in broken vertebrae and hemorrhaging. The head/heart method begins with a head-only stun, which the first, fourth, and seventh authors have observed to not typically cause petechial hemorrhages at 313 V of constant output. The second stage is applied separately to the head-only stun, and the primary muscles in the circuit are the intercostals. Because these muscles are much smaller than the longissimus thoracis, the contraction and resultant carcass damage is far less. This is part of the reason why petechial hemorrhages were not detected. In addition, our study was performed during a period of consistent ambient temperatures, which the fourth author has observed as a period of less petechial hemorrhage occurrence. Multiple factors influence petechial hemorrhages. Kirton and Frazerhurst (1983) found that season, time of day, and double stunning all affected petechial hemorrhages in lambs.

No difference \( (P > 0.05) \) was observed in CIE \( L^*a^*b^* \) color space values for longissimus thoracis, gluteus medius, or gluteus accessorius, 48 h postmortem longissimus thoracis pH, or 48 h drip loss percentage between stunning treatments (Table 3). A farm effect \( (P < 0.05) \) was observed in gluteus medius \( L^* \) value. Farm effects \( (P < 0.05) \) were also observed for CIE \( a^* \) and \( b^* \) values in longissimus thoracis, gluteus medius, and gluteus accessorius. Breed has been shown to affect pork drip loss and color stability (Edwards et al., 2003; Van Heugten et al., 2003). Hambrecht et al. (2004) cited preslaughter stress as a significant contributor to variation in fresh pork color and drip loss.

The head/heart method induced cardiac arrest and abolished righting reflex, eye tracking to moving objects, natural blinking, and rhythmic breathing. This method also significantly reduced the occurrence of involuntary nose twitch. Corneal reflex was observed in the majority of pigs in this study, regardless of stunning treatment. The recurrence of the corneal reflex in the present study merits further investigation, but the corneal reflex should not be used as an indicator of sensibility in pigs that have sustained cardiac arrest. Blood lactate concentrations were not different between stunning treatments. Objective measurement of meat color, drip loss, and pH did not identify meat quality differences between stunning treatments. Differences in blood lactate concentration, meat color, and drip loss were identified between farms of origin. These differences warrant further study of between-farm factors that influence these variables. This study has identified the head/heart method as a valid stunning procedure for small slaughter facilities to ensure maintenance of insensibility in electrically stunned pigs.

**Implications**

The maintenance of insensibility during pig slaughter is essential for compliance with humane slaughter regulations. In small slaughter facilities, where stun-to-bleed time is increased due to slow hoist speed, the
Table 3. Least squares means for stun treatment and farm effects on CIE L* a* b* color space values, 48-h postmortem pH, and 48-h drip loss of selected pork muscles

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Stun treatment</th>
<th>Farm effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Head</td>
<td>Head/heart</td>
</tr>
<tr>
<td>Longissimus thoracis, n = 23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L*</td>
<td>54.71</td>
<td>54.49</td>
</tr>
<tr>
<td>a*</td>
<td>18.39</td>
<td>18.93</td>
</tr>
<tr>
<td>b*</td>
<td>7.57</td>
<td>6.92</td>
</tr>
<tr>
<td>48-h postmortem pH</td>
<td>5.58</td>
<td>5.53</td>
</tr>
<tr>
<td>48-h drip loss, %</td>
<td>5.7</td>
<td>6.8</td>
</tr>
<tr>
<td>Gluteus medius (n = 82)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L*</td>
<td>50.41</td>
<td>50.65</td>
</tr>
<tr>
<td>a*</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>b*</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Gluteus accessorius (n = 82)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L*</td>
<td>43.38</td>
<td>43.54</td>
</tr>
<tr>
<td>a*</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>b*</td>
<td>5.72</td>
<td>5.64</td>
</tr>
<tr>
<td>2-way interactions</td>
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<tr>
<td>Gluteus medius</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a*</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Wk 1</td>
<td>19.63</td>
<td>19.95</td>
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<td>Wk 2</td>
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<td>Wk 3</td>
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<td>20.37</td>
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<tr>
<td>b*</td>
<td>4.52</td>
<td>4.17</td>
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<td>Wk 1</td>
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<td>5.14</td>
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<td>Wk 2</td>
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<td>5.34</td>
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<tr>
<td>Gluteus accessorius (n = 82)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a*</td>
<td>—</td>
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<td>Wk 1</td>
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<td>Wk 3</td>
<td>22.34</td>
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</tr>
</tbody>
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*Means under stun treatment or farm minimum and farm maximum within a row with unlike superscripts are different (P < 0.05).

Means for 2-way interactions within a column with unlike superscripts are different (P < 0.05).

Stun treatments: head: 6-s electrical stun applied behind ears; head/heart: 3-s electrical stun applied behind ears followed by 3-s electrical stun applied directly caudal to the forelimb and dorsal to the sternum.

Farm effects: pigs from 18 farms were included in gluteus medius and gluteus accessorius assessment. Seven farms were included in longissimus thoracis assessment. Maximum and minimum individual farm means are reported.

Interactions: 2-way interactions (week of study × stun treatment) observed for gluteus medius a* and b* values and gluteus accessorius a* values.

Head-only stunning method is not capable of rendering animals unconscious for an adequate period of time. A 2-stage stunning method, where a standard head-only stun is immediately followed by stunning wand application to the cardiac region of the chest of the pig, ensured the maintenance of insensibility during ensuing slaughter procedures. This stunning procedure had a very distinct advantage to render pigs unconscious and insensible to pain because heartbeat, rhythmic breathing, natural blinking, eye tracking to a moving object, and righting reflex were all abolished by this method. However, a corneal reflex was present in the majority of pigs, regardless of stunning treatment. It is unlikely that the presence of a corneal reflex without additional signs of sensibility is indicative of consciousness on the part of the stunned animal (Blackmore and Newhook, 1982). However, additional research is necessary regarding the occurrence in brainstem reflexes after epileptiform activity and concurrent cardiac arrest in electrically stunned swine. Overall, no differences in meat quality or plant efficiency were recognized between stunning treatments. This study identifies the head/heart method as a more effective stunning method than the head-only method with regard to animal welfare.

**LITERATURE CITED**


