

# Comparing various euthanasia devices and methods on 8 and 12-week-old turkey hens

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**ABSTRACT** On-farm euthanasia of poultry is a necessity for minimizing disease spread and removing sick or injured birds to maintain optimum animal welfare. There are numerous methods that are approved for euthanasia of poultry by organizations like the American Veterinary Medical Association; however, all approved methods are not easily carried out on-farm or as effective as one another. Therefore, the objective of this study was to compare several captive bolt devices (Turkey Euthanasia Device, Zephyr-EXL, Jarvis Stunner, Experimental Crossbow), mechanical cervical dislocation (Broomstick method [BRM] and Koechner Euthanasia Device [KED]), and manual cervical dislocation (MAN) methods on 8 and 12-week-old turkey hens. Each method was assessed for impact on loss of brain stem reflexes, euthanasia success, and torn skin. The cervical dislocation techniques were also analyzed via radiograph for proper dislocation. Furthermore, each device was assessed for physical parameters. Turkeys ( $n = 1,400$ ) were euthanized on 20 sampling days,

10 sampling days for each age period. All methods resulted in euthanasia of all turkeys in this study. The captive bolt devices all resulted in immediate loss of nictitating membrane and pupillary reflex at both the ages tested. The cervical dislocation methods differed in both nictitating membrane and pupillary reflex cessation at both ages ( $P < 0.05$ ). The pattern was the same at both ages with the KED device have longer latencies to cessation of both reflexes when compared to the BRM and MAN methods ( $P < 0.05$ ). Cessation of movement was also generally longer in dislocation methods compared to captive bolt at both ages. However, captive bolt devices resulted in more lacerations of the skin in general. MAN was also found to result in less damage to the vertebrae and proper location of separation than the mechanical methods of dislocation. All methods resulted in effective euthanasia; however, captive bolt methods resulted in immediate loss of brain stem reflexes indicating that they maybe more humane than cervical dislocation methods.

**Key words:** turkey, euthanasia, captive bolt, cervical dislocation

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## INTRODUCTION

On-farm euthanasia methods are a necessity for the prevention of disease outbreak and continuous suffering of injured or sick birds (Sparrey et al., 2014). There are numerous methods for euthanizing turkeys; however, not all are easily performed or as effective as others. Culling methods should minimize pain and distress and result in rapid insensibility and death via loss of respiratory function and cardiac arrest (Woolcott et al., 2018). Birds are routinely euthanized to prevent disease outbreak from spreading or to remove sick or injured

birds from the flock. Death via euthanasia may result from one or all of the following: hypoxia or reduced blood flow to the brain, physical disruption of total brain function leading to loss of respiratory function and cardiac arrest (AVMA, 2020).

According to AVMA (2020), penetrative and non-penetrative captive bolts, blunt force trauma, mechanical and manual cervical dislocation (MAN), injectable anesthetics including barbiturates, and gas inhalation via carbon dioxide, carbon monoxide, nitrogen, and argon are approved methods of euthanasia for poultry (AVMA, 2020). Both mechanical cervical dislocation and MAN, however, are most effective on small birds (under 3 kg) and injectable anesthetics and blunt force trauma are usually limited for laboratory settings (Woolcott et al., 2018). The 2 main methods used for routine on-farm killing of poultry are non-penetrating captive bolt or cervical dislocation (Martin et al., 2018a). Cervical dislocation causes death by cerebral

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ischemia and damage to the spinal cord and brain (Bader et al., 2014; Martin et al., 2018a). Successful euthanasia for MAN is when the first cervical vertebrae are completely separated and detached from the skull. Mechanical cervical dislocation crushes the cervical vertebrae inducing anoxia or loss of blood flow to the brain. Non-penetrating captive bolts cause death by concussive force which disrupts brain function for vital organs causing loss of respiratory function and cardiac arrest (AVMA, 2020). MAN can cause operator fatigue when utilized frequently and has loss of efficacy over time (AVMA, 2020) and use of non-penetrating captive bolt requires proper placement of the device.

Techniques used to evaluate the efficacy of particular euthanasia methods are pupillary light reflex, nictitating membrane reflex, and spinal reflexes. The pupillary light reflex and nictitating membrane reflex are considered to be an indicator of insensibility. Light when directed into the eye of a live animal will cause the pupil to constrict; when the light is removed the pupil will expand (Croft, 1961; Erasmus et al., 2010a). The nictitating membrane is a pale colored, semi-translucent membrane that protects the animal from getting contaminants on the cornea and maintains eye moisture (Martin et al., 2018a). When assessing insensibility via the nictitating membrane response, the eye is physically touched, following which the nictitating membrane will move to cover the cornea in a live animal. Insensibility is ascertained when the nictitating membrane ceases to respond (Sparrey et al., 2014). Additionally, cessation of convulsions is a reliable method for assessing complete brain failure (Dawson et al., 2009). Flexor reflex is the response of nociceptors activation to an applied physical pressure. When there is complete cessation of the nictitating membrane reflex and the pupil becomes fixed, blood flow to the brain is constricted leading to brain death (Erasmus, 2009).

The objective of this study was to compare the efficacy of 4 non-penetrating captive bolt devices, the Zephyr-EXL (ZEP), Turkey Euthanasia Device, Jarvis pneumatic stunner (JAR), and the Experimental Crossbow (CRS). Additionally, 3 types of cervical dislocation methods including MAN, Koechner Euthanasia Device (KED), and the Broomstick method (BRM) were also evaluated. Efficacy was based on antemortem signs of insensibility and clinical signs of death. We predicted based on limited reports that captive bolt devices will induce rapid insensibilities and death compared to all forms of cervical dislocation methods with all methods resulting in acceptable euthanasia.

## MATERIALS AND METHODS

### Ethical Note

Turkeys were managed according to the Guide for the Care and Use of Agricultural Animals in Research and Teaching [20] guidelines. All experimental methods were approved by the Texas A&M Institutional Animal Care and Use Committee (AUP #2018-0355).

### Overview

The study was conducted using commercially grown turkey hens within 2 age groups, 8 and 12-week-old (N = 1,400) hens. This experiment consisted of 7 treatments: ZEP, JAR, CRS, Turkey Euthanasia Device (TED), KED, from MAN, and BRM. Turkeys were tested on 20 separate experimental days over the course of 6 mo, from 4 separate grow-out facilities near Texas A&M University. Each experimental day included 1 of the 2 age groups and 10 birds per treatment were euthanized on each testing day.

### Captive Bolt Devices

Non-penetrating captive bolt devices (Figure 1), with the exception of the CRS, were attached to a Porter-Cable pancake air compressor (Porter-Cable, Jackson, TN) with the pressure set to 125 Psi. ZEP from Bock Industries (Elkhart, IN) is a pneumatic-powered non-penetrating captive bolt, with a mushroom-shaped head attached to a metal bolt. JAR from Jarvis Products Corp. (Middletown, CT), similar to ZEP, is a pneumatic-powered non-penetrating captive bolt device. The device powers a metal-alloy cylindrical bolt with a flattened bolt head. The Turkey Euthanasia Device (TED) from Bock Industries is a fuel-powered non-penetrating captive bolt (Hitachi NT65GS), containing a flat, steel bolt head. CRS from Koechner Mfg. Co. (Tipton, MO) consisted of a modified crossbow. The crossbow contained a steel bolt with a plastic cylindrical flattened bolt head, and was powered by a cocking lever. The draw weight of the crossbow was confirmed to be 36.3 kg.

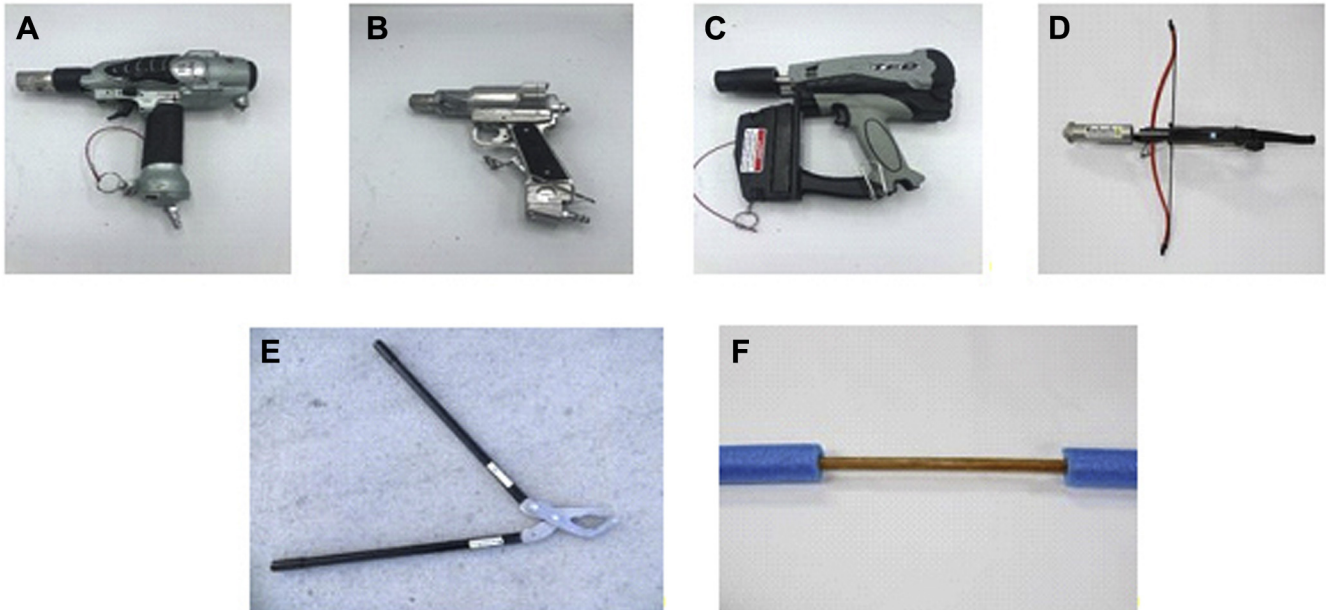
Each captive bolt device was applied according to previous research protocols (Erasmus, 2009; Woolcott et al., 2018). One shot was fired on top of the skull between the eyes and center to the ears (Woolcott et al., 2018). The ZEP, JAR, and the Turkey Euthanasia device were all powered with 120 psi across both age groups of turkeys in order to maintain consistency and achieve proper euthanasia.

### Cervical Dislocation Methods

MAN was performed by experienced personnel according to AVMA (2020) guidelines. Two methods of mechanical cervical dislocation were assessed (Figure 1). The KED from Koechner Mfg. Co. had a 102-cm length handle with metal jaw apparatus designed for cervical dislocation. The BRM had a 1-m length broomstick handle, with two 36-cm pool noodle foam inserts on both ends. Pool noodle foam inserts were placed onto the broomstick handles to reduce pain and distress from handling prior to application.

### Euthanasia Procedures

Turkeys in 2 age groups were tested in this study, 8 and 12-week-old. Each captive bolt device was tested



**Figure 1.** Euthanasia devices: (A) Zehphyr-EXL, (B) Jarvis Stunner, (C) Turkey Euthanasia Device, (D) Experimental Crossbow, (E) Koechner Euthanasia Device, and (F) Broomstick method.

on 10 birds per trial with a total of 10 trials per age group. Each turkey was placed on the floor in a sternal recumbent position with the keel on a solid flat table (Martin et al., 2018a). The birds were restrained by one person holding the legs and wings to prevent kicking and wing flapping while recording insensibility measures. Each device was discharged onto the top of the skull. Impacts were cranial to the ears, caudal to the eyes in accordance with previous research (Erasmus et al., 2010a).

When performing cervical dislocation, both mechanical and manual methods required the operator to maintain control of the wings and legs after application until sensibility parameters ceased. When using MAN, turkey heads were rotated in a cranial to caudal fashion until separation of the vertebrae was completed. Each cervical dislocation method was tested on 10 birds per trial with a total of 10 trials per age group. When operating the KED, the bird's head was made to rest on a flat surface, with the neck fully stretched. The jaws of the device were lined up with the base of the skull. Once the jaws of the device and skull were aligned, the handles were closed rapidly cervically dislocating the vertebrae from the skull. When performing the BRM, the turkey heads should be rested on a flat surface with the broomstick placed on top of the next/base of the skull. Once the placement of the skull and broomstick were aligned, the operator stepped on the broomstick with both feet while simultaneously pulling the turkey's legs upward until dislocation was achieved.

### **Insensibility Parameters**

Immediately following euthanasia via a device/method, turkeys were observed for pupillary light reflex, nictitating membrane reflex, and cessation of movement

(Table 1). All reflexes were checked every 5 s until cessation of movement was confirmed. All insensibility parameters were recorded in time (s) using a Fastime stopwatch (Leicestershire, United Kingdom). Time was recorded immediately following an attempt until complete cessation of each parameter, respectively.

### **Postmortem Data Collection**

Turkey heads and necks were visually inspected for punctures or lacerations immediately following death. Turkeys that presented lacerations or punctures were recorded within the age group and device/method used, respectively (N = 700). Turkeys euthanized via MAN or mechanical cervical dislocation were cut at the base of the neck (last cervical vertebrae), identified, and placed into a box for transportation. Turkey necks and skulls were radiographed at the Texas A&M University Veterinary Hospital and analyzed for correct vertebrae separation and to determine if the individual vertebrae were crushed for both 8-week-old (N = 300) and 12-week-old (N = 300) turkeys. All radiographed turkey necks/heads that were euthanized via cervical dislocation were viewed and scored as a percentage of occurrence (Table 2).

### **Euthanasia Device Physical Parameter Analysis**

To determine the minimum, maximum, average impact pressure (psi), and impact radius (cm), each device was fired 100 times with every tenth time onto a pressure film (Fujifilm High Prescale Film, 7,100–18,300 psi, Fujifilm, Valhalla, NY). The pressure films were then analyzed using a flatbed scanner (Epson V570, Epson America, Inc., Los Alamitos, CA) and

**Table 1.** Descriptions and procedures carried out according to previous research (Woolcott et al., 2018).

Measure	Description	Procedure
Nictitating membrane Reflex	Ephemeral closure of the nictitating membrane in response to physical stimulation	The medial canthus of the eye was gently touched with the fingertip
Pupillary Light reflex	Constriction of the pupil when exposed to light	Light source from a medical pen was shown directly into the eye
Cessation of movement (tonic)	Final episodes of movement including body convulsions and wing flapping	Observing the animal until complete cessation of movement

Fujifilm Pressure Distribution Mapping System (FPD-8010E, version 1.0, Fujifilm). The bolt velocity was determined by using a high-speed camera (Fastcam SA5, Photron USA, Inc., San Diego, CA) and accompanying analysis software (PFV3, Photron USA, Inc.). Each device was fired 10 times to get an average velocity. Kinetic energy (joules) was then calculated using the formula: kinetic energy =  $\frac{1}{2}$  (bolt mass) (velocity)<sup>2</sup>.

### Statistical Analysis

All analyses were performed using SAS 9.1 for Windows (SAS Institute Inc., Cary, NC). Because all data were ordinal, they were compared using the Kruskal-Wallis test on the equality of the medians, adjusted for ties. When significant differences were found, the Dwass-Steele-Critchlow-Fligner method (Hollander and East, 1999) was used to test for all possible comparisons. All sampling days were combined for each age group as no differences were found between testing days ( $P > 0.05$ ). Means are presented in all tables. The unit of measure was bird (for all insensibility and postmortem measures) or individual device firing (for euthanasia device physical parameter) and each device was a treatment group; testing days were not found to be significantly different and therefore were combined for all analyses.

## RESULTS

### Physical Parameters

Differences were observed in the average pressure of captive bolt devices ( $P < 0.05$ ). The TED device resulted in the highest average pressure compared to all devices (Table 3), while the CRS was observed to have the lowest average pressure ( $P < 0.05$ ). Additionally, the average kinetic energy was observed to be the

highest with the TED device compared to all other devices, and the CRS had the lowest average kinetic energy ( $P < 0.05$ ).

### Insensibility Parameters

Results of the cessation of movement, nictitating membrane, and pupillary reflexes for 8-week-old turkeys are presented in Table 4. Turkeys euthanized via captive bolt method did not present nictitating membrane reflexes or pupillary light reflexes. Cervical dislocation methods resulted in prolonged nictitating membrane and pupillary reflexes ( $P < 0.05$ ) when compared to captive bolt methods. Among the cervical dislocation methods, KED demonstrated the longest latency of the nictitating membrane response ( $119.07 \pm 4.05$  s) compared to MAN and BRM cervical dislocation ( $P < 0.05$ ). Similar results were seen with the pupillary response time, with the cervical dislocation methods showing lasting responses ( $P < 0.05$ ) while captive bolt devices resulted in immediate cessation. The KED maintained a longer latency to cessation of pupillary response ( $119.59 \pm 4.64$  s) than the MAN or BRM methods ( $P < 0.05$ ). Movement persisted for the longest duration in the cervical dislocation methods ( $P < 0.05$ ), with KED showing the longest latency ( $184.68 \pm 3.33$  s) until cessation. The CRS and TED captive bolts maintained the shortest latency to cessation of movement ( $P < 0.05$ ).

Nictitating membrane reflex, pupillary light response, and cessation of movement for turkeys at 12 weeks-of-age euthanized via captive bolt and cervical dislocation methods are listed in Table 5. Similar results were seen for turkeys aged 12 wk. The average time of the nictitating membrane response was highest when using the cervical dislocation methods ( $P < 0.05$ ) compared to all captive bolt devices. Upon comparing within cervical

**Table 2.** Descriptions for each type of postmortem data collection; all scores were recorded on a presence or absence basis.

Parameter	Description	Presence	Absence
Laceration/puncture	Postmortem observation of cutaneous tearing or penetration	External skin hemorrhage	No visual signs of cutaneous penetration
Location of separation	Inspecting the location of cervical vertebrae separation	The primary cervical vertebrae (C1) was completely detached from the skull	Any cervical vertebrae completely separated other than the C1 vertebrae
Separated vertebrae crushed	Separated vertebrae were inspected for signs of damage or crushing	Separated vertebrae that were crushed or broken	Separated vertebrae that were completely intact without being cracked/broken/crushed

**Table 3.** Captive bolt performance (pressure data were collected using Fujifilm pressure paper and software; speed and kinetic energies were recorded using a Vicon motion high speed camera).

Device <sup>1</sup>	Minimum pressure (psi)	Maximum pressure (psi)	Average pressure (psi)	Impact radius (cm)	Average bolt speed (m/s)	Average kinetic energy <sup>2</sup> (joules)
ZEP	20.30 <sup>a</sup>	71.1 <sup>b</sup>	41.35 <sup>c</sup>	0.20 <sup>b</sup>	67.76 <sup>b</sup>	143.16 <sup>b</sup>
JAR	18.10 <sup>b</sup>	92.4 <sup>a</sup>	30.70 <sup>d</sup>	0.40 <sup>a</sup>	60.76 <sup>b</sup>	127.71 <sup>b</sup>
CRS	18.9 <sup>b</sup>	92.4 <sup>a</sup>	54.24 <sup>b</sup>	0.40 <sup>a</sup>	49.10 <sup>c</sup>	108.93 <sup>c</sup>
TED	16.00 <sup>c</sup>	92.8 <sup>a</sup>	66.70 <sup>a</sup>	0.18 <sup>b</sup>	71.02 <sup>a</sup>	958.54 <sup>a</sup>
<i>P</i> -value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

<sup>a-d</sup>Indicates significant difference within the column ( $P < 0.05$ ).

<sup>1</sup>Treatments: Zephyr-EXL (ZEP); Jarvis Stunner (JAR); Turkey Euthanasia Device (TED); Experimental Crossbow (CRS).

<sup>2</sup>Kinetic energy =  $\frac{1}{2}$  (bolt mass) (bolt velocity<sup>2</sup>).

dislocation methods, the KED indicated the longest latency before cessation of the nictitating membrane response ( $138.28 \pm 3.20$  s) compared to MAN and BRM cervical dislocation ( $P < 0.05$ ). Comparing the pupillary response time, the cervical dislocation methods resulted in lasting responses ( $P < 0.05$ ), while captive bolt devices resulted in immediate cessation. The KED demonstrated longer latency to cessation of pupillary response ( $140.71 \pm 3.25$  s) than MAN or BRM methods ( $P < 0.05$ ). Movement reflexes persisted the longest in cervical dislocation methods ( $P < 0.05$ ), with the KED showing the longest latency ( $198.62 \pm 3.40$  s) until cessation. The CRS ( $152.24 \pm 5.11$  s), JAR ( $163.28 \pm 4.76$  s), and TED ( $151.81 \pm 3.89$  s) captive bolt devices were found to have the shortest latency to cessation of movement compared to all other euthanasia devices/methods ( $P < 0.05$ ).

### Postmortem Data Collection

Turkeys at 8 wk of age that were euthanized via cervical dislocation were evaluated and scored (Table 6) based on the location of the separated vertebrae and whether the separated vertebrae were crushed/damaged. Turkeys cervically dislocated manually resulted in the highest instances of C1 vertebrae separation (100%), and lowest instances of damaged/crushed vertebrae (10%) than BRM and KED methods ( $P < 0.05$ ). While BRM and KED methods were not significantly different, KED resulted in the least amount of C1 vertebrae separation (92%), and more instances of damaged/crushed vertebrae.

Cutaneous penetration of turkeys at 8 wk of age had the highest occurrence (100%) with TED compared to

all other devices/methods ( $P < 0.05$ ). JAR (56%) and ZEP (59%) had the second highest occurrences among captive bolts ( $P < 0.05$ ), at just above 50% of the total birds showing signs of cutaneous penetration. CRS showed the lowest instances of penetration of all captive bolts ( $P < 0.05$ ) with occurrences happening in only 35.35% of turkeys. KED resulted in the most instances of lacerations ( $P < 0.05$ ) among cervical dislocation methods (43.43%). There were no instances where MAN caused cutaneous lacerations (0%); therefore, MAN showed the lowest instances of all devices/methods ( $P < 0.05$ ).

Results of turkeys at 12 wk of age that were observed for laceration or punctures after application of devices/methods are listed in Table 7; additionally listed are results of turkeys that were cervically dislocated, radiographed, and analyzed for the location of separation and crushed/damaged vertebrae. Cutaneous penetration of turkeys at 12 wk of age resulted in TED and ZEP maintaining the highest occurrence (100%) compared to all other devices/methods ( $P < 0.05$ ). JAR (73%) and CRS (71%) had the lowest occurrences of penetration among captive bolts ( $P < 0.05$ ). KED resulted in the most instances of lacerations ( $P < 0.05$ ) among cervical dislocation methods (36%). There were no instances where MAN caused cutaneous lacerations (0%), resulting in MAN having the lowest instances of all devices/methods ( $P < 0.05$ ).

Turkeys cervically dislocated manually resulted in the highest instances of C1 vertebrae separation (100%), and lowest instances of damaged/crushed vertebrae (79%) than BRM and KED methods ( $P < 0.05$ ). Following MAN, BRM maintained the second highest instance of C1 vertebrae separation (29%); however,

**Table 4.** Insensibility responses and death of turkeys at 8 wk of age.

Treatment <sup>1</sup>	Nictitating membrane response (s)	Pupillary light response (s)	Cessation of movement (s)
KED	$119.07 \pm 4.05^a$	$119.59 \pm 4.64^a$	$184.68 \pm 3.33^a$
BRM	$73.70 \pm 3.39^b$	$72.78 \pm 2.12^b$	$168.40 \pm 4.28^{a,b}$
MAN	$71.95 \pm 3.12^b$	$68.08 \pm 3.31^b$	$166.97 \pm 4.16^{b,c}$
ZEP	IMED	IMED	$148.08 \pm 3.86^{c,d}$
JAR	IMED	IMED	$148.29 \pm 4.25^{c,d}$
TED	IMED	IMED	$138.53 \pm 3.99^d$
CRS	IMED	IMED	$139.23 \pm 3.79^d$

<sup>a-d</sup>Indicates significant difference within the column ( $P < 0.05$ ).

Abbreviation: IMED, immediate cessation.

<sup>1</sup>Treatments: Koechner Euthanasia Device (KED); Broomstick method (BRM); Manual Cervical Dislocation (MAN); Zephyr-EXL (ZEP); Jarvis Stunner (JAR); Turkey Euthanasia Device (TED); Experimental Crossbow (CRS).

**Table 5.** Insensibility responses of turkeys at 12 wk of age.

Treatment <sup>1</sup>	Nictitating membrane response (s)	Pupillary light response (s)	Cessation of movement (s)
KED	138.28 ± 3.20 <sup>a</sup>	140.71 ± 3.25 <sup>a</sup>	198.62 ± 3.40 <sup>a</sup>
BRM	111.19 ± 3.61 <sup>b</sup>	117.96 ± 4.91 <sup>b</sup>	191.82 ± 4.69 <sup>a,b</sup>
MAN	98.63 ± 3.88 <sup>b</sup>	109.00 ± 4.00 <sup>b</sup>	185.39 ± 4.56 <sup>b,c</sup>
ZEP	IMED	IMED	176.90 ± 4.55 <sup>c</sup>
JAR	IMED	IMED	163.28 ± 4.76 <sup>d</sup>
TED	IMED	IMED	151.81 ± 3.89 <sup>d</sup>
CRS	IMED	IMED	152.24 ± 5.11 <sup>d</sup>

<sup>a-d</sup>Indicates significant difference within the column ( $P < 0.05$ ).

Abbreviation: IMED, immediate cessation.

<sup>1</sup>Treatments: Koechner Euthanasia Device (KED); Broomstick method (BRM); Manual Cervical Dislocation (MAN); Zephyr-EXL (ZEP); Jarvis Stunner (JAR); Turkey Euthanasia Device (TED); Experimental Crossbow (CRS).

KED resulted in more ( $P < 0.05$ ) crushed/damaged vertebrae (95%) than BRM (70%).

## DISCUSSION

This study compared the efficacy of 4 non-penetrating captive bolt devices and 3 cervical dislocation methods on 2 age groups of turkey hens to determine if they induced rapid insensibility and death. Each device/method resulted in successful euthanasia in all turkeys of 8 and 12 wk of age indicating that all methods were acceptable methods of euthanasia of hens at these ages. Some studies have reported unsuccessful attempts of euthanasia using captive bolt devices (Woolcott et al., 2018), contrary to what was observed in this current study as all birds in the current study were successfully euthanized in one attempt. When performed successfully, captive bolt devices induce traumatic brain injury. Traumatic brain injury physically disrupts regions of the brain that control vital organ function (Andriessen et al., 2010). During an unsuccessful attempt, the skull of the animal may not have been penetrated or vital sections of the brain remained untouched. Reasons for failure included loss of air pressure within the device, and inaccurate location of application. It is recommended that operators inspect air compressors and gas canisters prior to euthanasia attempt (Woolcott et al., 2018). Captive bolt devices are designed to decrease the need for physical restraints; however, restraint may be needed to reduce injury and increase visual esthetics when performing on-farm euthanasia within the poultry barn. Relatively high success rates have previously been

observed with successful euthanasia occurring with one attempt 90 and 100% of the time (Hulet et al., 2013; Gibson et al., 2017; Woolcott et al., 2018). When done correctly, this method is highly effective.

Studies have reported successful euthanasia in turkeys euthanized by cervical dislocation; however, higher rates of successful euthanasia have been observed using MAN than mechanical cervical dislocation (Erasmus et al., 2010a,b; Woolcott et al., 2018). When performed correctly, cervical dislocation should sever carotid arteries, jugular veins, and dislocate the C1 cervical vertebrae from the skull causing brain ischemia and loss of brain function to vital organs (Martin et al., 2018b). Other studies have confirmed similar success rates with cervical dislocation (Erasmus et al., 2010a,b; Martin et al., 2018b) to what was observed in this current study. While cervical dislocation is considered as a preferred option due to its relatively low cost and practicality, some operators may have difficulty performing this method especially on older and larger birds. While the AVMA (2013) lists cervical dislocation as an approved method for birds weighing less than 3 kg, not all operators are physically capable of applying the method successfully. All turkeys euthanized via cervical dislocation in this study were restrained by hand, which may be difficult for certain operators.

When comparing the physical parameters of each captive bolt device, TED resulted in the greatest pressure and kinetic energy compared to all devices ( $P < 0.05$ ). The power source of the device may be the reason for the substantial increase in power compared to the bowstring of the CRS and the air pressure of the

**Table 6.** Postmortem analysis of turkeys at 8 wk of age (all data were recorded as a percentage of occurrence).

Treatment <sup>1</sup>	Separated vertebrae crushed (%)	Location of separation (%)	Lacerations or punctures (%)
KED	92.00 <sup>b</sup>	8.00 <sup>b</sup>	43.43 <sup>b,c</sup>
BRM	94.00 <sup>b</sup>	13.00 <sup>b</sup>	11.00 <sup>d</sup>
MAN	10.00 <sup>a</sup>	100.00 <sup>a</sup>	00.00 <sup>c</sup>
ZEP	N/A	N/A	59.00 <sup>b</sup>
JAR	N/A	N/A	56.00 <sup>b</sup>
TED	N/A	N/A	100.00 <sup>a</sup>
CRS	N/A	N/A	35.35 <sup>c</sup>

<sup>a-e</sup>Indicates significant difference within the column ( $P < 0.05$ ).

Abbreviation: N/A, data not applicable.

<sup>1</sup>Treatments: Koechner Euthanasia Device (KED); Broomstick method (BRM); Manual Cervical Dislocation (MAN); Zephyr-EXL (ZEP); Jarvis Stunner (JAR); Turkey Euthanasia Device (TED); Experimental Crossbow (CRS).

**Table 7.** Postmortem analysis of turkeys at 12 wk of age (all data were recorded as a percentage of occurrence).

Treatment <sup>1</sup>	Separated vertebrae crushed (%)	Location of separation (%)	Lacerations or punctures (%)
KED	95.00 <sup>c</sup>	5.00 <sup>e</sup>	36.00 <sup>d</sup>
BRM	70.00 <sup>b</sup>	29.00 <sup>b</sup>	3.00 <sup>e</sup>
MAN	21.00 <sup>a</sup>	100.00 <sup>a</sup>	0.00 <sup>e</sup>
ZEP	N/A	N/A	100.00 <sup>a</sup>
JAR	N/A	N/A	73.00 <sup>b,c</sup>
TED	N/A	N/A	100.00 <sup>a</sup>
CRS	N/A	N/A	71.00 <sup>e</sup>

<sup>a-e</sup>Indicates significant difference within the column ( $P < 0.05$ ).

Abbreviation: N/A, data not applicable.

<sup>1</sup>Treatments: Koechner Euthanasia Device (KED); Broomstick method (BRM); Manual Cervical Dislocation (MAN); Zephyr-EXL (ZEP); Jarvis Stunner (JAR); Turkey Euthanasia Device (TED); Experimental Crossbow (CRS).

ZEP and JAR. Additionally, the small bolt head attached to the TED device might have resulted in the higher average pressure. Cutaneous penetration was mostly observed when using captive bolt devices. TED resulted in the most instances of penetration across both age groups. Bolt design may have an impact on cutaneous penetration. The occurrences of penetration were found to be consistent with the bolt head design. The ZEP bolt head was designed with a pointed rubber tip; while this increased the depth of brain trauma, it also increased the percentage of cutaneous penetration. The CRS and JAR both have flat bolt heads, leading to a decrease in penetration percentages. The bolt head of the TED may have led to the increase in instances because of its small diameter (19.1 mm) and hard steel material. Published studies have confirmed that captive bolts result in greater percentages of penetration, with ZEP (93%) and TED (92%) both resulting in cutaneous penetration (Woolcott et al., 2018). Additionally, higher instances of skin penetrations may be due to the kinetic energy of the TED device. With an average kinetic energy of 958.54 J, TED has the greatest amount of energy per shot and may lead to increased penetration. Higher percentages of penetration were found in turkeys at 12 wk of age. Higher instances of penetration may have occurred due to skull fractures breaking the skin. While younger turkeys have thinner, malleable skulls, older turkeys have more rigid intact skulls which can lead to sharp fractures that penetrate the skin (Woolcott et al., 2018).

Pupillary light and nictitating membrane responses have been used as reliable, practical on-farm euthanasia measures for determining insensibilities and brain death (Erasmus, 2009; Martin et al., 2018b). Sandercock et al. (2014) reported that cessation of the nictitating reflex and pupillary light response were representative of bird death. An electroencephalography analysis of these measures was confirmed (Sandercock et al., 2014) and therefore selected as a measure of brain death and proper euthanasia in this study.

These antemortem measures demonstrated that captive bolt devices are capable of performing successful euthanasia without the presence of any sensibilities. The absence of pupillary light response and nictitating membrane reflex when using captive bolt devices was consistent in similar studies (Erasmus et al., 2010a,b; Martin

et al., 2018b; Woolcott et al., 2018). Pressures in psi used in this study were slightly higher (120 psi) to create a similar impact to the CRS and TED, in which the impact pressure of the devices was fixed. Compared to other similar studies, psi pressures were slightly lower at 100 to 115 psi (Woolcott et al., 2018), which may suggest that greater percussive force caused greater destruction of brain function resulting in immediate brain death.

Cervical dislocation methods when performed resulted in extended pupillary and nictitating membrane responses. These latencies may be caused by the absence of brain trauma, with damage occurring to the carotid arteries and brain stem (Martin et al., 2018b). With death occurring via brain ischemia, consciousness may be overserved for several seconds post application. Studies assessing cervical dislocation methods demonstrated similar results (Martin et al., 2018b; Bandara et al., 2019). Mechanical cervical dislocation (KED) resulted in an increased latency to cessation of the nictitating and pupillary light reflexes. The objective for cervical dislocation is to dislocate the neck at the highest point (C0–C1) and sever carotid arteries; however, mechanical cervical dislocation was found to only cause dislocation or disruption of the spinal cord increasing the latency to ischemia and brain death (Martin et al., 2018b).

Cessation of movement which is an indicator of death was observed with all applications of euthanasia. Cessation of movement following the use of captive bolt devices resulted in shorter latencies, which may be due to the severity of brain trauma induced. Woolcott et al. (2018) demonstrated how certain captive bolt devices induce rapid cessation of movement based on the severity of skull fractures and brain trauma. Turkeys after a failed euthanasia attempt were shown to have less brain and skull destruction (Woolcott et al., 2018). Older age turkeys (12 wk) resulted in increased latencies to cessation of movement than their younger counterparts (8 wk), which may have been the result of greater bone development of the skull (Woolcott et al., 2018). Additionally, previous head injuries, device misplacement, and operator skill may cause variability to latencies of death.

Cervical dislocation methods resulted in increased latencies to cessation of movement. This may be due to the

lack of brain trauma that occurs when applying this method type. MAN resulted in a shorter latency to cessation compared to the KED and BRM methods. Results were similar to other studies, which demonstrated that MAN (twisting, pulling motion) severed both carotid arteries while mechanical cervical dislocation (crushing) severs only one or neither artery (Erasmus, 2009; Martin et al., 2018a; Bandara et al., 2019). Additionally, movement was observed to have greater latency in the 12-week-old turkeys. This may be a result of greater skeleton development; as a bird's age increases, the vertebrae may become fused to the base of the skull which will increase the amount of connective tissue within that area (McLeod et al., 1964; Martin et al., 2018a). The fused vertebrae may have decreased the rate of brain death.

Lacerations on the neck of turkeys were seen most when using mechanical cervical dislocation, specifically the KED method. The KED was designed to have steel jaws; while durability and ease of use are proponents, they may also lead to a greater percentage of cutaneous tearing. When performing MAN, the operator can physically "sense" the separation of vertebrae and halt the stretching, while in KED and BRM methods the sensation is not felt. Younger turkeys (8 wk) should have higher percentages of lacerations, which may be indicative of the size of the vertebrae. The range of motion may have had a greater impact on the percentages of lacerations occurring in young turkeys. Jacobs et al. (2019) demonstrated similar results with mechanical cervical dislocation. The mechanical cervical dislocation method (KED) resulted in more external skin damage in layer chickens compared to MAN (Jacobs et al., 2019).

Analysis of the radiographed turkeys resulted in higher percentages of crushed/damaged vertebrae in birds euthanized via the KED. This is due to the KED method of crushing the vertebra to create the separation. MAN separated the vertebrae via twisting and stretching, which resulted in a higher percentage of complete separation. Erasmus et al. (2010a) demonstrated similar results with Birdizzo, where the device dislocated the turkeys' necks by crushing. While some studies have resulted in poor euthanasia rates (Erasmus et al., 2010a,b; Martin et al., 2018a), all turkeys in this study were successfully euthanized. Poor euthanasia rates for mechanical cervical dislocation have been reported in the AVMA (2020), in which mechanical cervical dislocation is not an approved method.

Additionally, mechanical cervical dislocation resulted in fewer instances of C1 vertebra separation. Specific placement of the KED device was required for C1 separation. The design of the KED device resulted in separation of the vertebra further down the spine. When applying the KED device, proper placement of the head within the jaws was difficult to achieve when operating singularly. Bandara et al. (2019) reported similar results with the KED device size not proportional to the turkey size. Mechanical cervical dislocation efficacy

may be the result of the size of the animal and device model utilized, while MAN efficacy is a direct result of the specific operator's skill.

## CONCLUSION

All captive bolt devices met the strict requirements for euthanasia success. Based on these results, captive bolt devices are considered the most reliable form of on-farm euthanasia when performed properly by trained operators. Captive bolts demonstrated immediate insensibilities while decreasing the latency to cessation of movement (death) compared to mechanical cervical dislocation and MAN methods. Additionally, the TED and CRS devices allow an advantage with regards to portability. CRS resulted in immediate cessation of sensibilities and similar latencies to cessation of movement to captive bolts. Its use is also advantageous for on-farm use due to the absence of a power source allowing substantial use before required mechanical servicing. The TED also may be overpowered, and its head may be too focused on a small area as it resulted in penetration of the skull making it visually unappealing while still effectively euthanizing the bird. While the CRS is considered in this study as the most reliable method, this device is still experimental as well as issues of wear and maintenance should be studied further. Overall because the captive bolt devices resulted in immediate cessation of brain reflexes they are likely more humane than cervical dislocation methods.

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## DISCLOSURES

There is no conflict of interest.

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