Livestock raised in commercial settings may require euthanasia for many reasons (eg, disease, injury, or an excess of males in a dairy herd). In the dairy goat industry, there is currently limited information available regarding feasible and cost-effective methods for euthanizing goat kids that are safe for use by producers. Without that information, the welfare of dairy goats is likely compromised because inappropriate euthanasia methods may be used. The term euthanasia is derived from the Greek words eu and thanatos meaning ‘good death’ and is commonly used to describe the ending of an animal’s life with minimal pain and distress.1 The primary objective of euthanasia is to cause rapid loss of consciousness that is sustained until death.2 To cause loss of consciousness and sufficient brain damage that leads to death, the cerebral hemispheres and brainstem (comprising the midbrain, pons, and medulla oblongata, which are responsible for life functions such as cardiac and respiratory activity) must be damaged. Acceptable methods of euthanasia consistently produce a humane or good death, whereas unacceptable methods are deemed inhumane or pose risks to the operator. Acceptable methods of euthanasia for sheep and goats as described by the AVMA Panel on Euthanasia include a lethal overdose of a barbiturate, gunshot, and penetrating or nonpenetrating captive bolt devices.1 Barbiturates generally induce a smooth transition to unconsciousness and death and can be beneficial in many settings.2 However, a barbiturate overdose can only be administered by or under the direct supervision of a licensed veterinarian, which can increase the costs associated with euthanasia and proper disposal of the carcass (ie, incineration).1 Physical methods of euthanasia, such as gunshot and captive bolt, cause immediate loss of consciousness followed by death, but effective use of those methods is dependent on the anatomic landmarks used and the directional aim of the device.2 A danger associated with the use of firearms is that a bullet may travel through the skull of the animal and put the operator and other bystanders at risk of injury. Therefore, safe and effective euthanasia methods for small goat kids that can be administered by producers are warranted.

The use of a nonpenetrating captive bolt device to deliver consistent and controlled blunt force trauma to the skull causes rapid loss of consciousness and consequent death in 48-hour-old,3 1-week-old,4 and 3-week-old5 goat kids. However, those devices are expensive (ranging from $800 to $1,600), which has limited their adoption by the North American goat industry, there is currently limited information available regarding feasible and cost-effective methods for euthanizing goat kids that are safe for use by producers. Without that information, the welfare of dairy goats is likely compromised because inappropriate euthanasia methods may be used.

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dairy goat industry. Goat producers need and desire a more cost-effective method for euthanizing young kids. One such method might be use of a multipump air pistol, which is often used to shoot (euthanize) vermin. The pellet fired by an air pistol is less likely than a bullet from a firearm to exit the skull and ricochet into bystanders. Additionally, air pistols are fairly inexpensive (approx $40), compared with nonpenetrating captive bolt devices, and can be purchased without a firearms license.

The objective of the pilot study reported here was to assess the extent of damage to the skull and brain of cadaveric goat kids induced by pellets fired from a multipump air pistol at half (5 pumps), intermediate (7 pumps), and full (10 pumps) power. We hypothesized that pellets fired at full power, but not at half power, would cause sufficient damage to the brainstem to result in death and that the extent of brainstem damage induced by pellets fired at intermediate power would be less than that induced by pellets fired at full power, but greater than that induced by pellets fired at half power.

Materials and Methods

Sample

The study involved the cadavers of 15 goat kids (8 male and 7 female) that were ≤ 5 days old at the time of euthanasia for reasons unrelated to the study. Because the study did not involve the use of live animals, it was exempt from institutional animal care and use committee review. A power analysis and sample size calculation were not performed because the study was intended to be a pilot project. The number of cadavers assessed was determined on the basis of availability from the source farm.

All cadavers were acquired from 1 commercial dairy goat operation in Iowa. The owner of that operation was also a licensed veterinarian. All kids were euthanized with sodium pentobarbital (1 mL/4.5 kg, IV) by the owner-veterinarian as part of routine management practices for the operation.

Experimental design

All experimental procedures were performed within 6 hours after the kids were euthanized (ie, the cadavers were fresh at the time of experimental manipulation). A uniquely numbered plastic tag was applied to 1 ear of each cadaver for identification purposes. Each cadaver was enrolled in 1 of 3 treatment groups on the basis of the order in which they were presented to the researchers by the owner. The treatment groups were defined by the power with which the pellet was shot from the pistol, which was determined by the number of manual pumps applied to the pistol prior to its firing. The pistol was manually pumped 5, 7, and 10 times prior to firing each pellet for the half, intermediate, and full power groups, respectively.

All treatments were administered by use of a multipump air pistol that fired a .22-caliber pellet, which weighed approximately 16 g. Prior to study initiation, a chronometer was used to measure the actual velocity of the pellet as it left the muzzle of the pistol at each of the 3 evaluated power levels. Five pellets were shot at each of the 3 power levels. The mean muzzle velocity was 101.4 m/s for pellets shot at half power, 113.6 m/s for pellets shot at intermediate power, and 124.1 m/s for pellets shot at full power. Given the weight of the projectile (pellet), those velocities equated to a ballistic (muzzle) energy of 5.4 to 8.1 J, which was well below the ballistic energy of a .22-caliber bullet fired by rifle (approx 190 J) and the kinetic energy of a nonpenetrating (27.8 J) or penetrating (65.7 J) captive bolt.

The assigned treatments were applied to all cadavers within a 1-hour period that began at approximately 3 pm. Each cadaver was positioned in sternal recumbency with the head and neck extended on a bale of straw. A piece of cardboard was placed under the head and neck to facilitate the determination of whether the pellet exited the skull. The anatomic target for pellet placement was the top of the head at the intersection of 2 imaginary lines that extended from the lateral canthus of each eye to the middle of the contralateral ear base (Figure 1) as described for a study in which adult goats were euthanized by use of a penetrating captive bolt device. The air pistol was held perpendicular to and 2.5 cm from the head as determined by a measurement guide (metal rod) that was attached to the barrel of the pistol in a manner that would not affect the trajectory of the pellet (ie, the pellet traveled parallel to the measurement guide after it was fired). Per the AVMA Guidelines for the Euthanasia of Animals, the muzzle of the pistol was not held flush against the head of the cadaver because to do so would increase the pressure within the barrel when the pistol was fired, which might cause the barrel to explode and cause injury to the operator or bystanders.

Each treatment was observed by the shooter (PJP) and another investigator (MNH) who was responsible for recording data, both of whom were aware of the treatment applied to each cadaver (ie, the observers were not blinded). Following treatment application, the head and neck of each cadaver was removed from the rest of the carcass at the base of the neck (ie, where the neck meets trunk) and wrapped with plastic wrap to prevent accumulation of air within the tissues. The heads were refrigerated (storage temperature, approx 7°C) for approximately 24 hours until they underwent CT imaging.

CT imaging

All CT images were acquired by use of a 16-slice multidetector CT scanner. Each cadaveric head was placed in a ventral position and parallel to the long axis of the image gantry in a manner similar to that used for live patients. Scans were performed by use
of 0.5-mm-thick isotropic voxels and reformatted into 1-mm-thick slices in transverse, dorsal, and sagittal planes for image reconstruction and assessment. All images were reviewed on a dedicated workstation with commercially available medical imaging software by a board-certified veterinary radiologist (JLF) who was blinded to the treatment assignment for each head.

**Gross assessment**

Following completion of CT imaging, the heads were cut in half along the midsagittal plane with an electric band saw. The sections were then photographed with a digital camera, and the photographs were used to facilitate interpretation of the CT images. Originally, we intended to use the photographs to evaluate and score the extent of gross physical damage and disruption to the brain. However, this was not possible because the pellet and the tract it created were not visible in all heads owing to variation in the trajectory of the pellets and the plane in which the heads were sectioned. The thickness of each skull immediately adjacent to the pellet entry point was measured with Vernier calipers.

**Statistical analysis**

Descriptive data were generated, but formal statistical analyses were not performed. This was a pilot study that was conducted with the intent of generating data to inform the design of future studies.

**Results**

Descriptive information for each of the 15 cadaveric heads is available elsewhere (Supplementary Table S1, available at: avmajournals.avma.org/doi/suppl/10.2460/ajvr.81.11.866). A skull fracture was present at the pellet entry site in 14 of the 15 cadaveric heads; the pellet was lodged within the skin of the remaining head. The head that did not have a skull fracture at the pellet entry site was from a male kid that was shot with the air pistol at half power (5 pumps); the mean ± SD skull thickness was 3.00 ± 0.16 mm for that kid. The mean ± SD skull thickness for all 15 heads was 1.88 ± 0.16 mm; however, the mean ± SD skull thickness for male kids (2.13 ± 0.26 mm) was numerically greater than that for female kids (1.61 ± 0.17 mm). The pellet penetrated the brainstem of 7 of 14 heads with evidence of pellet entry into the skull and 5 of the 11 heads that were shot at high power (10 pumps; Figure 2). In the remaining 7 cadavers, the pellet was observed in the superficial portion of the parietal lobe of the cerebrum (n = 2) or in the temporal lobe of the left cerebral hemisphere (2), or it penetrated the base of the skull (3).

**Discussion**

The objective of the pilot study reported here was to assess the extent of damage to the skull and brain of cadaveric dairy goat kids caused by a .22-caliber, 16-g pellet fired from a multipump air pistol at half (5 pumps; n = 2), intermediate (7 pumps; 2), and full (10 pumps; 11) power. The pellet breeched the skull in 14 of the 15 cadavers assessed; for the remaining cadaver, the pellet was shot from the pistol at half power and became lodged in the skin. This suggested that use of the air pistol at half power was insufficient to consistently penetrate the skull of dairy goat kids ≤ 5 days old. The thickness of the skull at the anatomic target region may have affected whether the pellet...
Figure 2—Representative transverse CT images (A through D) and photograph of a sagittal section (E) of the skulls of dairy goat kid cadavers that were shot with a multipump air pistol at full power as described in Figure 1. All CT images were acquired at the level of pellet entry into the skull. The pellet (arrow) appears as a large white star-shaped feature because of beam-hardening artifact; the black voids within the cranial space are gas bubbles along the pellet's trajectory after it entered the skull. A—Transverse CT image of the skull of a female goat kid with a skull thickness of 1.25 mm. The pellet was located in the left temporal lobe with extension into the rostroventral aspect of the squamous temporal bone, but did not penetrate the brainstem. B—Transverse CT image of the skull of a female goat kid with a skull thickness of 1.25 mm. The pellet was located medial to the left mandibular ramus and did not penetrate the brainstem. C—Transverse CT image of the skull of a male goat kid with a skull thickness of 2.5 mm. The pellet was located medial to the left mandibular ramus and did not penetrate the brainstem. D—Transverse CT image of the skull of a female goat kid with a skull thickness of 1.25 mm. The pellet was lodged in the left mid-basisphenoid bone. E—Photograph of a sagittal section of the skull of the cadaver represented in panel D. Notice that the pellet (black circle) penetrated the brainstem (bracket). For all CT images, right is to the left side of the image.
was able to penetrate it. The anatomic target region of the skull was 3.0 mm thick for the cadaver in which the pellet failed to penetrate the skull, which was 3 times the thickness of the anatomic target region of the skull (1.0 mm) for the other cadaver that was shot at half power, in which the pellet penetrated the skull as well as the brainstem. To our knowledge, the present study was the first to measure skull thickness of dairy goat kids ≤ 5 days old. Aside from affecting the efficacy of various euthanasia methods, skull thickness also contributes to the risk of adverse effects associated with cautery disbudding, which is commonly performed in kids < 1 week old.6 The use of cautery irons for disbudding goat kids can lead to thermal and bacterial meningoencephalitis7-10 and the probability of those deleterious conditions occurring is likely a function of skull thickness.

In the present study, the pellet entered the skull and became lodged in the brain when the air pistol was fired at intermediate (n = 2 heads) and full (11) power. However, the pellet penetrated the brainstem in only 1 of 2 heads shot at intermediate power and 5 of 11 heads shot at full power. This suggested that the method described in the study reported here may not consistently cause death in dairy goat kids ≤ 5 days old. Results of an audit of US abattoirs published in 2010 indicated that the first stunning attempt rendered 95% of animals processed through those facilities immediately insensible.11 Since then, the euthanasia failure rate for goat kids following use of a captive bolt device has been estimated as 2%4 or 3%.3 Given those percentages, the multipump air pistol method described in this study does not appear to be an acceptable stand-alone method for euthanizing goat kids, even when the pistol is fired at full power, because the pellet penetrated the brainstem (necessary for immediate death) less than half the time.

Failure of the air pistol pellet to penetrate the brainstem and cause sufficient damage to ensure death in over half of the heads assessed in the present study may have been the result of multiple factors. Of the 14 heads in which the pellet successfully penetrated the skull, the pellet was found in the left cerebral hemisphere and completely missed the brainstem in 7 heads. This may have been the result of failure to maintain the barrel of the pistol at a perpendicular angle to the head, which has been previously identified as a limiting factor for effective euthanasia.2 The length of the air pistol used in the present study, in addition to the acenptic placement and size of the barrel (relative to the anatomic target region on the head), further complicated aiming of the pistol to ensure proper pellet trajectory. Although the shooter tried to consistently maintain the barrel perpendicular to the target area, there was substantial variation in the final location of the pellet within the skull of the assessed heads. Thus, inconsistent aiming of the barrel toward the brainstem appeared to be a limiting factor for the euthanasia method described in this study. An automated mechanism or device (instead of a person) that could hold the air pistol in place might improve the consistency of muzzle orientation relative to the anatomic target region and consequent penetration of the brainstem by the pellet.

It is also possible that the size or caliber of the pellet used in the present study was too small to consistently ensure sufficient brain damage to cause death owing to physical factors as well as the release of kinetic energy. The AVMA Guidelines for the Euthanasia of Animals1 recommend that a .22-caliber long-range rifle be used to euthanize sheep and goats. The maximum velocity of the pellet fired from the air pistol might have affected the resultant brain damage. The maximum velocity of pellets fired from the air pistol used in this study was 124.1 m/s, whereas the maximum velocity of bullets fired from a .22-caliber long-range rifle ranges from 349.9 to 381.9 m/s.12 For the air pistol used in the present study, the maximum velocity of the pellets resulted in a kinetic energy that was one-fifth to one-tenth that reported for nonpenetrating captive bolt devices.12 Nonpenetrating captive bolt devices cause rapid acceleration and deceleration of the brain in addition to rotational and shearing (ie, concussive) forces within the cranial cavity, and penetrating captive bolt devices cause traumatic brain injury characterized by penetrating lesions.12 Additionally, for the heads assessed in the present study, the pellet did not fragment after it penetrated the skull, which limited its ability to cause brain damage, compared with bullets (eg, hollow-point bullets) that are designed to fragment after impact.12 However, that conclusion requires 2 assumptions. The first of those assumptions is that the pellet travels in a straight trajectory after leaving the pistol and does not ricochet within the calvarium. The second assumption is that energy propagation within the cranial cavity secondary to the penetrating pellet is negligible, compared with that induced by application of nonpenetrating captive bolt devices. If either of those assumptions is false, it is possible that the combination of direct penetrating trauma to the cerebral cortices and potential for intracranial ricochet of the pellet with resultant energy propagation through the brain tissue might be adequate for euthanasia.

Several anatomic targets have been described for application of euthanasia methods in goats. For euthanasia of adult goats, anatomic targets used for application of a penetrating captive bolt device include the intersection of 2 imaginary lines that extend from the lateral canthus of an eye to the middle of the contralateral ear base (ie, the same anatomic target used for the goat kid cadavers of the present study)2 and the dorsal midline at the external occipital protuberance (poll) of the skull.13 Use of a penetrating captive bolt device for euthanasia of neonatal goat kids poses a safety risk because the bolt might exit the ventral aspect of the skull and impact an unintended object. Nonpenetrating captive bolt devices are effective for
euthanizing goat kids up to 4 weeks old when applied to the poll with the neck held in extreme flexion (ie, with the rostral aspect of the mandible tucked against the thoracic inlet) so that the brainstem is positioned in a more superficial location and more likely to sustain direct physical damage from application of the device.3–5 In the present study, the necks of the cadavers were not held in a flexed position owing to safety concerns associated with requiring the shooter to have their hand in close proximity to the trajectory of the pellet. The anatomic target used for the cadavers of this study would permit live kids to be restrained by mechanical means (eg, disbudding box) instead of the shooter’s hand. Additionally, for the cadavers assessed in this study, the air pistol pellet did not exit or fragment within the calvarium, which confined the induced damage to a localized area and minimized the risk of collateral damage.

To our knowledge, the present study was the first to evaluate the extent of skull and brain damage in dairy goat kids induced by a pellet fired from a multipump air pistol. However, this study was not without limitations. Ideally, a more standardized method would have been used to position and orient the barrel of the air pistol so that the pellet consistently penetrated the brainstem. For example, a freestanding device that was fixed to the floor or a restraint device could have been used to orient the barrel of the pistol in the same position for firing the pellet in all cadavers, which may have facilitated placement of the pellets into the heads in a more uniform manner and increased the likelihood of damaging the brainstem.

Results of the present study indicated that the described euthanasia technique (use of a multipump air pistol to fire a .22-caliber, 16-g pellet into the skull at the intersection of 2 imaginary lines that extended from the lateral canthus of each eye to the middle of the contralateral ear base) lacked sufficient energy to consistently damage the brainstem and cause the immediate death of dairy goat kids ≤ 5 days old. Thus, the use of a multipump air pistol as described in this study does not appear to be an acceptable stand-alone method for euthanizing young dairy goat kids. Further research is warranted in which the described technique is modified by maintaining the muzzle in a standard orientation relative to the head, altering the anatomic landmark used for pellet placement, or using an air pistol capable of generating a greater muzzle velocity than the pistol used in this study.

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The authors declare that there were no conflicts of interest.

Footnotes
a. TED (turkey euthanasia device), Bock Industries, Krugersdorp, South Africa.
b. Strike Point multipump pellet pistol, Umarex USA Inc. Fort Smith, Ark.
c. Polymag 16-g pellet, Predator International Inc, Littleton, Colo.
e. Aquilion-16, Canon Medical Systems USA Inc, Tustin, Calif.
f. eFilm, version 4.2.2, Merge Healthcare, Chicago, Ill.
g. Coolpix L840, Nikon Inc, Tokyo, Japan.

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