The do's and don'ts of bovine euthanasia

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Introduction

The goal of humane euthanasia is to produce a "good death" by inducing a rapid, ideally instantaneous, loss of consciousness followed quickly by respiratory and cardiac arrest. Bovine euthanasia often presents significant challenges due to the size and nature of the animal, limited options for euthanasia methods, facility limitations and operator experience among many others. In particular, euthanasia under field conditions may present unique challenges. Developing a plan, or standard operating procedure, can reduce the risk of adverse events and help ensure both the welfare of the animal being euthanized and the personnel performing the task. However, the varied circumstances under which bovine euthanasia may be needed can require adaptability and flexibility. Veterinarians and other individuals performing euthanasia should be familiar with standard euthanasia practices and be comfortable with a variety of euthanasia methods to allow adaptability to ensure the welfare of animals requiring euthanasia under a variety of circumstances. The purpose of this paper is to provide practical tips on the do's and don'ts of humane bovine euthanasia under a variety of circumstances.

Euthanasia methods

One of the most basic requirements for effective and humane euthanasia is familiarity with available methods of euthanasia. The 2020 edition of the AVMA Guidelines on Euthanasia[a] provides a detailed description of the approved methods of euthanasia for cattle.

Barbiturate overdose (pentobarbital)

Intravenous injection of pentobarbital is probably the most familiar method of euthanasia for most veterinarians and is the most common euthanasia method for companion animal species. Pentobarbital is the only fully acceptable euthanasia method per the AVMA Guidelines. Pentobarbital injection typically results in a rapid and smooth progression from consciousness to unconsciousness and death. Even though pentobarbital injection is very effective, its use comes with many challenges and limitations. Effective use requires intravenous injection which requires good restraint and technical skill. Pentobarbital is a controlled substance and, therefore, is not available for use by non-veterinarians. Cost can also be an issue due to the large volumes required for euthanasia of adult cattle. Pentobarbital residues in carcasses limit carcass disposal options and environmental residues are a growing concern. Environmental residues from pentobarbital euthanasia are discussed in more detail below.

Firearm or gunshot

Euthanasia via gunshot is acceptable according to the AVMA Guidelines as long as certain conditions are met. When performed correctly, gunshot euthanasia results in instantaneous loss of consciousness due to massive destruction of brain tissue. Firearms are generally readily available in livestock production areas. Firearm euthanasia can be performed without close animal restraint if necessary. The large number of firearm types, calibers and bullet types provide a large array of effective options but can also lead to confusion and uncertainty when it comes to choosing the best firearm for euthanasia. Firearm euthanasia may often be perceived as violent, and the aesthetics are less than that typically associated with pentobarbital euthanasia. Safety concerns and operator comfort, and legal use restrictions are the primary limitations to firearm euthanasia.

Penetrating captive bolt

The use of a penetrating captive bolt (PCB) provides an effective and somewhat safer method of euthanasia compared to the use of a firearm. The use of a PCB is listed as acceptable with conditions according to the AVMA Guidelines. The advantages of PCB compared to a firearm include increased safety and fewer legal restrictions. Captive bolt devices are not considered firearms and can be used legally in most locations where firearm use may be prohibited. Safety concerns do certainly exist with a PCB but those concerns are significantly less than the concerns associated with firearm use. The primary limitation to PCB bolt use is that a PCB is considered a stunning tool and a secondary follow-up step to ensure death is strongly recommended. This need can increase the time, and technical skill, required to perform euthanasia, particularly if large numbers of animals are involved. Another limitation is the need for adequate restraint. Shot placement is critical for effective PCB use and the device must be held in firm contact with the animal's head at the time of the shot.

Adjunctive methods

The application of an adjunctive method to ensure death is strongly recommended following PCB euthanasia and may be applied after firearm use as well. It is important to note that the adjunctive methods described below should only be applied to unconscious animals. They are not approved for the euthanasia of conscious animals.

Intravenous injection of concentrated solutions of potassium chloride (KCL) or magnesium sulfate (MGS) will interfere with the electrical conductivity of the heart and lead to cardiac arrest. Generally, 60 to 180 mls injected into the jugular vein is adequate in most adult cattle. Potassium chloride can be purchased in the form of salt substitutes.

Exsanguination leads to cardiac failure due to hypoxia and volume depletion. Severing the carotid arteries and jugular veins results in rapid blood loss but creates a significant mess and

could create biosecurity concerns. Internal exsanguination can be performed by using a scalpel blade to sever the distal aorta via the rectum.

Pithing results in additional destruction of brain tissue making recovery of consciousness impossible. The pithing rod is placed through the hole created by the PCB and causes additional destruction of brain tissue. Pithing is the author's preferred adjunctive step. It can be performed very rapidly and requires less skill than intravenous injection. The author's preferred device is an 18-21-inch plastic uterine infusion pipette. These pipettes have enough flexibility to pass through the foramen magnum disrupting the brainstem and much of the proximal spinal cord. Involuntary jerking of the carcass usually occurs during pithing so the technique is aesthetically unpleasing. Pithing may also expose the operator to central nervous system tissues and fluids. A second shot from a PCB can be used as a form of pithing.

Do's and don'ts of bovine euthanasia

The remainder of this document describes several DO's and DON'T's of bovine euthanasia. The intent is to provide a series of tips to help veterinarians and their clients be prepared so that euthanasia can be performed as timely as possible while ensuring the welfare and safety of both the animal and the individual performing the euthanasia.

DO – be prepared

Cattle producers, regardless of operation size, need to have a euthanasia plan. Large producers such as feedlots and dairies typically have euthanasia standard operating procedures (SOPs) with specific individuals trained to perform the task. It is always a good idea for the herd veterinarian to review these SOPs and provide revisions and training whenever needed. Small producers are not immune from the need for a euthanasia plan. The need for euthanasia often arises outside of normal business hours or during other emergency situations, so producers should be equipped to perform euthanasia humanely if their veterinarian is not available in a timely manner. Euthanasia plans for small producers may be as simple as a description of the most appropriate firearm based on what is available to the producer and a description of appropriate shot placement. When employees are going to be making euthanasia decisions and performing euthanasia, more detailed SOPs are likely indicated.

DON'T – use pentobarbital

Injection of pentobarbital sodium is the primary method of euthanasia for small animals and horses and is still the primary method used by many bovine veterinarians. A recent Canadian survey found that pentobarbital was the method most commonly used by veterinarians to euthanize dairy cows.[1] Most veterinarians are likely familiar with the concerns over harmful chemical residues that remain in carcasses when animals are euthanized with pentobarbital. Secondary poisoning of a variety of species related to the ingestion of pentobarbital containing meat or carcasses has been reported.[2–8] Due to concerns regarding secondary poisoning, carcasses with pentobarbital residues must undergo proper disposal. Rendering, composting, and burial are the most commonly used methods for carcass disposal in livestock production settings.

Carcasses containing pentobarbital residues cannot be rendered which may create concerns for large feedlots or dairies where rendering is still an option for carcass disposal. Pentobarbital has been shown to survive the rendering process[9] and pet intoxication from contaminated food has been reported[b]. For small producers, rendering is no longer an option in most locations and burial or composting are commonly recommended methods of carcass disposal.

Pentobarbital is a very stable compound, and it appears to remain in the environment for long periods of time. Multiple researchers have examined the persistence of pentobarbital concentrations in compost when euthanized horses are composted. Payne et al.[10] found that pentobarbital concentrations in compost remained high for at least 367 days. The authors noted no discernable trend in pentobarbital degradation over the 367 days of the study. They also noted that pentobarbital leached through the compost and was detectable in the soil below the compost pile on day 367. More recently, Lochner et al.[11] found that pentobarbital remained detectable in equine compost piles for at least 216 days but the estimated quantity of pentobarbital was reduced by approximately 94%. Differences in study design and the compost substrate used may account for the variations in findings. It is important to note that the concentrations of pentobarbital found in both studies are unlikely to result in secondary toxicosis from ingestion.

Burial is a commonly used carcass disposal method. Each state has specific rules regarding how and where carcasses may be buried relative to ground and surface water. The risk of pentobarbital leaching from burial sites into ground water is unknown, but pentobarbital remains in tissues for long periods of time. Kaiser et al.[7] reported the intoxication of 2 dogs that scavenged a partially buried equine carcass that had been euthanized approximately 2 years earlier. Samples of some tissues from the equine carcass still contained high levels of pentobarbital residues. Bagsby et al.[12] found that pentobarbital remains detectable in various types of soil for at least 17 weeks. Pentobarbital stability in water is also a concern. Peschka et al.[13] found high stability of pentobarbital in aquatic environments over long periods of time.

Alkaline tissue hydrolysis is a less commonly used method of carcass disposal that is used by several diagnostic labs and research facilities. The process results in a liquid effluent that can be land applied or disposed of through municipal sewer systems. To the author's knowledge, no data is available to describe the effects of alkaline hydrolysis on pentobarbital degradation.

The long-term significance of even low concentrations of pentobarbital in the environment is unknown. Given the evidence that pentobarbital from euthanized animals persists in the environment for long periods of time, and its significance is unknown, veterinarians should move away from pentobarbital as a primary euthanasia method.

DO – become familiar with multiple euthanasia methods

Most veterinarians will have a preferred method for bovine euthanasia and that preferred method will be used in most situations. However, circumstances may dictate that an alternative method be used. Veterinarians should be able to switch to an alternative method quickly and seamlessly so that euthanasia is not delayed unnecessarily. A recent survey of Canadian veterinarians found that the majority of survey respondents use pentobarbital as the primary euthanasia method and that only 70% and 53% of respondents were comfortable advising clients on the use of a captive bolt or firearm, respectively.[1] Conversely, a

similar survey of Canadian dairy producers found that just over half of the producers surveyed used a firearm as the primary method of euthanasia.[14] An earlier survey of dairy farms in the United States found that gunshot was the preferred euthanasia method for 85.7% of the farms surveyed.[15] This survey was not specific to veterinarians but does provide information about euthanasia practices on U.S. dairy farms.

As discussed above, it would be prudent for the veterinary industry to move away from pentobarbital euthanasia. In order to accomplish that task, feasible alternatives are needed. Penetrating captive bolts or firearms are obvious alternatives to pentobarbital and are used by many veterinarians and cattle producers. However, these devices may not always be available and many individuals may not be comfortable with their use. Additionally, physical methods of brain destruction may not be appropriate for some cases due to the need to preserve the brain for diagnostic purposes or due to potential risk of exposing the operator to central nervous system tissues.

Unfortunately, there are no other currently approved methods of euthanasia for cattle when the animal is conscious. However, inducing deep general anesthesia prior to euthanasia opens the door to a few other possibilities. Once the animal is in a deep plane of surgical anesthesia, intravenous injection of KCL or MGS to cause cardiac arrest is an acceptable method of euthanasia. This is the author's preferred euthanasia method when gunshot or PCB cannot be used. The author prefers to use xylazine at 1.1 to 2.2 mg/lb (0.5 to 1 mg/kg) and ketamine at 13.2 to 17.6 mg/lb (6 to 8 mg/kg). These doses are higher than would be used for typical general anesthesia and help ensure that the animal is anesthetized as deeply as possible. While this method is not specifically described for cattle in the current AVMA Guidelines, it is described as an adjunctive method for equine euthanasia. An additional alternative to pentobarbital is the intrathecal injection of lidocaine under general anesthesia. The animal is deeply anesthetized as described above and approximately 60mls of lidocaine is injected intrathecally via the atlanto-occipital space. The author is not aware of any research using this method in cattle but it has been described in horses[16–19] and is listed as an adjunctive method for euthanasia of horses in the current AVMA Guidelines.

DON'T – administer adjunctive methods of euthanasia under xylazine alone

Although actual data are lacking, it seems to be common for adjunctive methods of euthanasia such as exsanguination or KCL injection to be performed under heavy sedation with xylazine alone. This method offers a significant advantage in that it avoids the use of controlled substances making it available for use by non-veterinarians. However, for adjunctive methods of euthanasia to be considered humane, the animal must be unconscious. Stanger et al.[20] investigated the euthanasia of sheep using pentobarbitone (pentobarbital), KCL or MGS after intramuscular administration of 0.88 mg/lb (0.4 mg/kg) xylazine. Conscious perception of pain was monitored via electroencephalography (EEG). The authors concluded that there was no evidence of perceived pain or unpleasant sensory experience for any of the treatments although the time to isoelectric EEG was prolonged for KCL and animals receiving KCL exhibited severe reflex movements during infusion. The authors concluded that all 3 methods were acceptable but that MGS was preferred over KCL. Conversely, a study investigating the level of unconsciousness induced by administration of high doses of xylazine to cattle was conducted by Dewell et al.[21] In this study, a total of 12.1 to 19.4 mg/lb (5.5 to 8.8 mg/kg) xylazine was administered in 3 doses over a 10-minute period and brain activity was measured via EEG. Even with these extremely high doses of xylazine, none of the study animals reached a surgical plane of anesthesia. Based on these results, the administration of adjunctive methods of euthanasia following xylazine alone cannot be recommended for cattle. The author has had good results with high doses of xylazine followed by high doses of ketamine prior to KCL injection.

DO – train producers to conduct PCB or firearm euthanasia

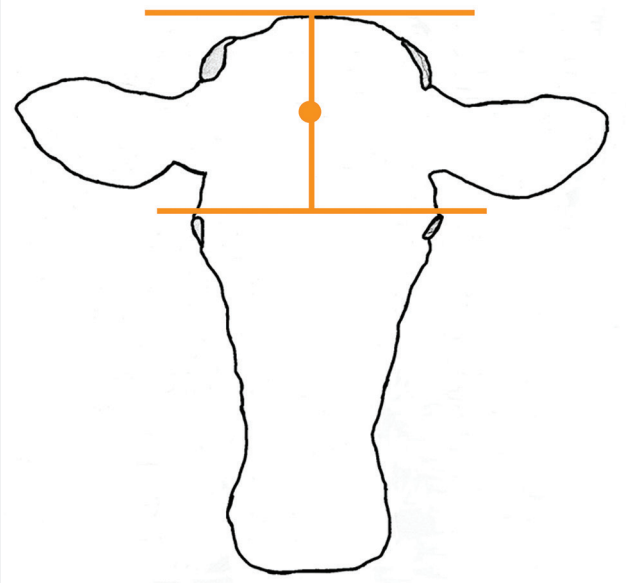
Veterinarians have access to a variety of effective euthanasia methods but the options for non-veterinarians are limited to PCB or gunshot. Pentobarbital is not an option for producers. Currently xylazine is not a controlled substance but, as described above, xylazine alone does not induce an adequate level of anesthesia prior to application of adjunct euthanasia methods. Ketamine is a controlled substance with high abuse potential, so its use is also limited to veterinarians. These limitations really leave PCB or gunshot as the only viable, currently approved, methods available to producers. A survey of British dairy producers and veterinarians found that 66% of farms did not have anyone on the farm staff that was trained to perform euthanasia.[22] As mentioned above, a survey of U.S. dairy farms found that 85.7% of farms preferred gunshot euthanasia but only 1 farm used a PCB.[15] However, 8% of the farms used intravenous injection as the primary euthanasia method. This was not a survey of veterinarians, so pentobarbital is unlikely to be the medication being injected, raising concern that non-approved substances were likely being injected as euthanasia agents. The authors stated that 3.5% of farms refused to disclose the euthanasia methods used. A survey of Canadian dairy producers found that a majority use a firearm as the primary euthanasia method but 34% of farms used blunt force as the primary euthanasia method for male dairy calves.[14] The results of these surveys indicate that the majority of farms in the U.S. and Canada are using appropriate euthanasia methods but there is still significant room for improvement.

Veterinarians should be the primary source of information and training regarding euthanasia. Given that PCB or gunshot are the only approved methods available to be used by producers or their employees, veterinarians need to at least have enough familiarity with these methods to provide training to their clients. Several authors have published information regarding PCB or gunshot euthanasia.[23–28]

Accurate shot placement is essential to effective euthanasia via PCB or gunshot. Several descriptions of shot placement have been published.[23,29–31] The author prefers shot placement described as a point on midline halfway between a line drawn across the back (lateral canthus) of the eyes and a parallel line drawn across the top of the poll (Figure 1). This description places the shot directly over the brainstem regardless of the shape of the head. Although the published descriptions vary, the actual shot placement described by the different authors is very similar. The AVMA Guidelines on Euthanasia provide detailed descriptions of shot placement along with excellent diagrams.

Given the huge variation in firearms and bullet types available and the fact that research specific to firearm euthanasia is lacking, choosing a firearm specifically for euthanasia can be challenging. A study by Baker et al.[32] evaluated several firearm and ammunition combinations. Unfortunately, this study is very limited due to the limited number of replications for each

Figure 1: Shot placement for PCB of gunshot described as midline halfway between a line drawn across the back of the eyes (lateral canthus) and a parallel line drawn across the top of the poll.



evaluation, but the authors did conclude that the majority of the firearm and ammunition combinations assessed were effective. Small caliber firearms such as the .22 long rifle were not effective. A more recent study evaluated various firearm and bullet combinations using isolated heads from feedlot cattle.[33] The authors of this study concluded that the .22 hollow-point and 9mm pistol were ineffective. The key factors to consider when choosing a firearm for euthanasia are having enough power to adequately penetrate the skull and brain and having a bullet that will retain enough mass upon impact to penetrate the skull and brain but still deliver kinetic energy into the tissue efficiently. Most firearms larger than a .22 will have enough power to penetrate a bovine skull. High powered rifles are overkill for most cattle and carry an increased risk of overpenetration. Hollow point bullets may fragment dramatically upon impact and may not penetrate the skull adequately. Full metal jacketed bullets retain their original shape upon impact and, therefore, create less tissue disruption. They also have a higher risk of over penetration and leaving the target animal creating a safety issue.

DO – confirm loss of consciousness or sensibility

Following gunshot or PCB, always confirm the loss of consciousness or sensibility as soon as safely possible. The primary signs of loss of sensibility are immediate collapse if the animal is standing, presence of a centered and dilated pupil and loss of all eye reflexes (especially the corneal reflex), lack of coordinated respiration or vocalization and lack of a righting reflex. Loss of sensibility should always be confirmed prior to application of any secondary or adjunctive method of euthanasia. If there is ever any doubt regarding the loss of sensibility, a second shot should be applied immediately.

DON'T – assume death

Always confirm that an animal is dead before leaving or moving the animal with equipment. As mentioned above, a secondary step to ensure death is strongly recommended, especially when using a PCB. A study[25] led by the author evaluated a single PCB shot without a secondary step. Cattle were shot with a PCB and then monitored for sensibility until cardiac arrest. All animals were adequately stunned and showed no signs of sensibility immediately after PCB. However, approximately 10% of the animals began to exhibit coordinated respiration prior to cardiac arrest. One animal showed no signs of sensibility for 8 minutes after PCB when it took a breath. When the brains of these animals were evaluated, the brainstem was missed due to slight errors in shot placement or shot angle. This study was relatively small but clearly indicates the continued need for a secondary step to ensure death following PCB. The author prefers to confirm the lack of an auscultable heartbeat and then wait 3 to 5 minutes and reconfirm that the heart has indeed stopped.

DO – use sedation to facilitate euthanasia

Although pentobarbital, PCB or gunshot euthanasia can all be performed without sedation, sedation may make the process easier and less stressful for both the animal and the operator. When using pentobarbital for euthanasia, there is some concern that sedation may lower blood pressure resulting in slower delivery of the drug to the brain and a longer euthanasia process. Barletta et al.[34] investigated the effect of dexmedetomidine sedation on quality of euthanasia in sheep. A small number of sheep vocalized in response to dexmedetomidine, but the sedation did not have any effect on the quality of the euthanasia event.

Since use of a PCB requires restraint and the device must be held in firm contact with the head, sedation may reduce stress on the animal and facilitate accurate shot placement. One of the primary advantages of sedation for ambulatory cattle is the ability to perform the euthanasia in a location that will facilitate carcass removal. Getting a euthanized bovine out of a chute or alley system can be difficult and time consuming. The author prefers to give approximately 500 mg of xylazine intramuscularly to adult cattle and then walk them to an area that will be accessible with equipment. The animals typically become recumbent and minimally responsive, facilitating euthanasia via PCB. Even those that remain standing are heavily sedated and minimally responsive.

DON'T – get kicked by a dead cow

During euthanasia via PCB or gunshot, sudden, uncoordinated limb movements can occur. When assessing an animal for sensibility, administering KCL or MGS, or assessing cardiac arrest, the operator should always position themselves on the dorsal side of the animal to avoid being injured should sudden limb movements occur.

DO – develop a plan for large-scale euthanasia

Hopefully, most veterinarians will never have to be involved in a mass euthanasia event. However, emergency events are unpredictable and occur without warning. Having a plan in place to conduct a large-scale euthanasia event before an emergency occurs can enhance the speed and quality of euthanasia and reduce stress on the operators. In the event of a depopulation event due to a disease, federal authorities will be in charge and the local veterinarian should only need to play a supporting role. Smaller-scale events such as natural disasters, intoxications or vehicle accidents could place the veterinarian in the position of leading a large-scale euthanasia event without much time for prior planning. The euthanasia of 32 cattle in response to an infectious disease outbreak has been described.[35] In this

report, cattle were individually restrained in a chute, sedated and euthanized via pentobarbital injection. The average time from entry into the chute until the confirmation of death was 5.2 minutes. One fractious animal required 27 minutes to complete the euthanasia process. Sedation of groups of animals followed by euthanasia via PCB or gunshot may be more practical for large groups of animals. Hanthorn et al.[36] described the euthanasia of 43 feedlot cattle due to an intoxication using xylazine sedation followed by gunshot. The entire euthanasia process was very efficient, only requiring 46 minutes from the first sedation to the last gunshot. Vehicle accidents involving livestock transportation vehicles may result in the need to euthanize multiple animals. Responding to this type of event appropriately can minimize negative welfare of injured animals but also reduce the risk of further property damage or loss of animal, or even human, life. Pederson et al.[37] published an excellent paper outlining the veterinarian's role in responding to truck accidents involving cattle.

Conclusions

Timely euthanasia of cattle is a vital component of the efforts to ensure animal welfare. Several methods of euthanasia are available. Some options are only available for use by veterinarians but effective and humane options are available for on-farm use by producers. Veterinarians should be comfortable with multiple euthanasia methods and should serve as the primary source of information and training for producers regarding euthanasia.

Footnotes

[a] **https://www.avma.org/sites/default/files/2020-02/Guidelines-on-Euthanasia-2020.pdf**

[b] **https://www.avma.org/javma-news/2017-04-01/pentobarbital-food-sickens-dogs-food-maker-wants- more-regulations**

References

1. Rousseau M, Descôteaux L, Denisrobichaud J, et al. Dairy cattle on-farm euthanasia: a survey of Canadian veterinarians' practices. *Proc Am Assoc Bov Pract Conf* 2020;395–395.

2. Fucci V, Monroe WE, Riedesel DH, et al. Oral pentobarbital intoxication in a bitch. *J Am Vet Med Assoc* 1986;188:191–192.

3. Gonzalez-Jassi HA, Jakobek B, Ebbott A, et al. Successful medical management of an acute case of pentobarbital toxicosis in a wild bald eagle (*Haliaeetus leucocephalus*). *Vet Rec Case Rep* 2022;10.

4. Herrero-Villar M, Sánchez-Barbudo IS, Camarero PR, et al. Increasing incidence of barbiturate intoxication in avian scavengers and mammals in Spain. *Environ Pollut* 2021;284.

5. Humphreys DJ, Longstaffe JA, Stodulski JBJ. Barbiturate poisoning from pet shop meat: possible association with perivascular injection. *Vet Rec* 107:517.

6. Jurczynski K, Zittlau E. Pentobarbital poisoning in Sumatran tigers (*Panthera tigris sumatrae*). *J Zoo Wildl Med* 2007;38:583–584.

7. Kaiser AM, McFarland W, Siemion RS, et al. Secondary pentobarbital poisoning in two dogs: a cautionary tale. *J Vet Diagn Invest* 2010;22:632–634.

8. Reid TC. Barbiturate poisoning in dogs. *N Z Vet J* 1978;26:190.

9. O'Connor JJ, Stowe CM, Robinson RR. Fate of sodium pentobarbital in rendered products. *Am J Vet Res* 1985;46:1721–1724.

10. Payne J, Farris R, Parker G, et al. Quantification of sodium pentobarbital residues from equine mortality compost piles. *J Anim Sci* 2015;93:1824–1829.

11. Lochner HL, Hutchinson ML, Wilson ML, et al. Characteristics and sodium pentobarbital concentrations of equine mortality compost piles in the upper midwest. *J Equine Vet Sci* 2022;114.

12. Bagsby C, Saha A, Goodin G, et al. Stability of pentobarbital in soil. *J Environ Sci Health B* 2018;53:207–213.

13. Peschka M, Eubeler JP, Knepper TP. Occurrence and fate of barbiturates in the aquatic environment. *Environ Sci Technol* 2006;40:7200–7206.

14. Roche SM, Genore R, Renaud DL, et al. Describing mortality and euthanasia practices on Canadian dairy farms. *J Dairy Sci* 2020;103:3599–3605.

15. Fulwider WK, Grandin T, Rollin BE, et al. Survey of dairy management practices on one hundred thirteen north central and northeastern United States dairies. *J Dairy Sci* 2008;91:1686–1692.

16. Aleman M, Davis E, Williams DC, et al. Electrophysiologic study of a method of euthanasia using intrathecal lidocaine hydrochloride administered during intravenous anesthesia in horses. *J Vet Intern Med* 2015;29:1676–1682.

17. Amaral LA, Rabassa V, Marchiori M, et al. Use of lidocaine hydrochloride 2% intrathecally associated with prior anesthesia with thiopental as a method of euthanasia in horses. *Ars Vet* 2011;27:11–16.

18. Guedes A, Aleman M, Davis E, et al. Cardiovascular, respiratory and metabolic responses to apnea induced by atlanto-occipital intrathecal lidocaine injection in anesthetized horses. *Vet Anaesth Analg* 2016;43:590–598.

19. Turner TA. When all else fails: alternative methods of euthanasia. *Vet Clin North Am Equine Pract* 2021;37:515–519.

20. Stanger KJ, Kells NJ, Fisher AD, et al. Evaluation of euthanasia of sheep with intravenous saturated salt solutions to enable the collection of whole, intact brains. *Anim Welf* 2019;28:397–406.

21. Dewell RD, Bergamasco LL, Kelly CK, et al. Clinical study to assess the level of unconsciousness in cattle following the administration of high doses of xylazine hydrochloride. *Proc Am Assoc Bov Pract Conf* 2014;183.

22. Neary JM, Bedford C, Smith RF. End-of-life decision-making of dairy cattle and calves: a survey of British farmers and veterinary surgeons. *Vet Rec Open* 2022;9.

23. Dewell RD, Dewell GA, Bear DA, et al. Description and justification of a consistent technique for euthanasia of bovines using firearm and penetrating captive bolt. *Bov Pract* 2016;50:190–195.

24. Dewell RD, Moran LE, Kleinhenz KE, et al. Assessment and comparison of electrocardiographic and clinical cardiac evidence of death following use of a penetrating captive bolt for euthanasia of cattle. *Bov Pract* 2015;49:32–36.

25. Gilliam JN, Woods J, Hill J, et al. Evaluation of the CASH Dispatch Kit combined with alternative shot placement landmarks as a single-step euthanasia method for cattle of various ages. *Anim Welf* 2018;27:225–233.

26. Griffin D. Feedlot euthanasia and necropsy. *Vet Clin North Am Food Anim Pract* 2015;31:465–482.

27. Shearer JK. Euthanasia of cattle: practical considerations and application. *Animals* 2018;8:57.

28. Shearer JK. Effective euthanasia of cattle under field conditions. *Proc Am Assoc Bov Pract Conf* 2008;92–96.

29. Collins SL, Kull J, Benham C, et al. Comparison of penetrating and non-penetrating captive bolt in an alternative occipital approach in calves. *Anim Welf* 2020;29:59–67.

30. Gilliam JN, Shearer JK, Bahr RJ, et al. Evaluation of brainstem disruption following penetrating captive-bolt shot in isolated cattle heads: comparison of traditional and alternative shot-placement landmarks. *Anim Welf* 2016;25:347–353.

31. Gilliam JN, Shearer JK, Woods J, et al. Captive-bolt euthanasia of cattle: determination of optimal-shot placement and evaluation of the Cash Special Euthanizer Kit® for euthanasia of cattle. *Anim Welf* 2012;21:99–102.

32. Baker HJ, Scrimgeour HJ. Evaluation of methods for the euthanasia of cattle in a foreign animal disease outbreak. *Can Vet J* 1995;36:160–165.

33. Thomson DU, Wileman BW, Rezac DJ, et al. Computed tomographic evaluation to determine efficacy of euthanasia of yearling feedlot cattle by use of various firearm-ammunition combinations. *Am J Vet Res* 2013;74:1385–1391.

34. Barletta M, Hofmeister EH, Peroni JF, et al. Influence of sedation on onset and quality of euthanasia in sheep. *Res Vet Sci* 2018;117:57–59.

35. Gilroyed BH, Reuter T, Kastelic JP, et al. Emergency euthanasia of cattle challenged with Escherichia coli O157:H7 - a case study for evaluating the response to an infectious disease outbreak. *J Vet Sci* 2013;14:103–106.

36. Hanthorn CJ, Sanderson MW. Xylazine sedation and gunshot for depopulation of cattle. *Bov Pract* 2020;53:166–168.

37. Pederson L, Yates J, Wieman A. Preparation and response to truck accidents on highways involving cattle. *Vet Clin North Am Food Anim Pract* 2018;34:289–307.

