Computed tomographic evaluation to determine efficacy of euthanasia of yearling feedlot cattle by use of various firearm-ammunition combinations

Daniel U. Thomson, DVM, PhD; Benjamin W. Wileman, DVM, PhD; Darrel J. Rezac, MS; Matt D. Miesner, DVM, MS; Jennifer L. Johnson-Neitman, DVM; David S. Biller, DVM

Objective—To evaluate with CT the efficacy of various combinations of firearms and ammunitions to penetrate and disrupt the brain tissue of cadaveric heads of feedlot steers.

Sample—42 fresh cadaveric heads of 12- to 18-month-old *Bos taurus* steers.

Procedures—For each of 7 combinations of firearms and ammunitions (.22-caliber rifle firing a long rifle 30-grain plated lead solid- or hollow-point round, .223-caliber carbine firing a 50-grain ballistic-tip round, 9-mm pistol firing a 124-grain total metal jacket round, .45-caliber automatic Colt pistol [ACP] firing a 230-grain full metal jacket round, and 12-gauge shotgun firing a 2.75-inch 1.25-ounce No. 4 birdshot shell or a 1-ounce rifled slug), 6 cadaveric heads were shot at an identical distance (3 m), angle, and anatomic location. Heads were scanned with third-generation CT, and images were evaluated to determine extent of penetration, projectile fragmentation, cranial fracture, and likelihood of instantaneous death (≥ 30% destruction of brain tissue or a brainstem lesion).

Results—41 of 42 skulls were penetrated by the projectile. Instantaneous death was considered a likely consequence for 83% (25/30) of heads shot with a rifle-fired .22-caliber solid-point round, pistol-fired .45-caliber ACP round, carbine-fired .223-caliber round, and shotgun-fired birdshot and slug. Of the 18 heads shot with pistol-fired 9-mm and .45-caliber ACP rounds and rifle-fired .22-caliber hollow-point rounds, only 6 had brainstem lesions.

Conclusions and Clinical Relevance—Results suggested that gunshots delivered by all firearm-ammunition combinations except rifle-fired .22-caliber hollow-point rounds and pistol-fired 9-mm rounds were viable options for euthanasia of feedlot cattle. (*Am J Vet Res* 2013;74:1385–1391)

The establishment of guidelines and protocols for the use of firearms in the euthanasia of cattle is essential because unsuccessful attempts at euthanasia are inhumane and demoralizing. Failure of euthanasia by gunshot can lead to operator reticence[1]; however, delaying the decision to euthanize an animal prolongs its suffering and, in regard to euthanasia for control of a catastrophic infectious or foreign animal disease outbreak, can slow depopulation efforts and thus potentially exacerbate the risk of infection for other animals.

Received January 19, 2013.
Accepted June 3, 2013.
From the Departments of Clinical Science (Thomson, Miesner, Johnson-Neitman, Biller) and Diagnostic Medicine and Pathobiology (Wileman, Rezac), College of Veterinary Medicine, Kansas State University, Manhattan, KS 66502. Dr. Wileman's present address is Epitopix LLC, 1801 Biotech Ave NE, Willmar, MN 56201.
Supported by the USDA APHIS.
Presented as an oral presentation at the 44th Annual American Association of Bovine Practitioners Meeting, St Louis, September 2011.
The authors thank Jacob Hagenmaier and Robert Munson for technical assistance.
Address correspondence to Dr. Thomson (dthomson@vet.ksu.edu).

Abbreviations

ACP	Automatic Colt pistol
KE	Kinetic energy

The use of firearms for the euthanasia and depopulation of cattle has precedence and is approved by both the AVMA[2,3] and the American Association of Bovine Practitioners.[4] Nevertheless, studies conducted to establish recommendations on which firearm and ammunition combinations routinely result in satisfactory euthanasia as well as minimize the risk of harm to operators and bystanders are lacking. The amount of energy that must be carried by a projectile to penetrate the skulls of various livestock species varies greatly.[5] The caliber of the firearm and the various properties associated with the round being fired play a major role in whether the projectile achieves sufficient penetration of the skull and produces lethal brain damage.[6] In 1 study,[6] 6 firearms and 11 types of ammunition were assessed to determine the effectiveness of the projectile to penetrate and cause brain tissue destruction in cattle; however, only 3 of the 11 trials performed had > 1 replicate, and there were insufficient data available for a valid statistical analysis. Effective skull penetration was not achieved in any of the trials that involved a .22-caliber long rifle in that study.[6] Results of other studies[7–9] indicate that the use of firearms for the euthanasia of sheep, cattle, and pigs is safe.

Novel approaches for the euthanasia of cattle in the field are necessary for many reasons. In the event of a catastrophic infectious or foreign animal disease outbreak in a geographic region densely populated with cattle, results of a simulation modeling study[10] suggest that the required euthanasia rate is approximately 3 times as great as the available capacity to perform euthanasia, which will exacerbate the magnitude of the epidemic. Estimates of the time required to depopulate a typical Midwestern beef feedlot by use of a conventional captive bolt range up to 80 days,[a] which is unacceptably slow in the event of an infectious disease outbreak. The use of firearms for euthanasia could help decrease the time required for depopulation of large numbers of cattle. Cattle populations are growing increasingly concentrated both by geographic region and the number of cattle per premises. This consolidation results in a high number of cattle having intimate contact with each other and their human caretakers, thus increasing the potential for foreign animal and zoonotic disease transmission. The consolidation of a greater number of cattle on fewer premises also increases the number of cattle per premises that will require euthanasia under normal production conditions. On a per-premises basis, approximately 0.4% of beef and dairy cattle will become nonambulatory at some time,[11] which means that large operations will likely have cattle with debilitating conditions that require euthanasia on a continuous basis, whereas smaller operations may rarely or only intermittently have a small number of cattle that require euthanasia.

The ban on the slaughter of nonambulatory cattle at commercial abattoirs has likely resulted in an increase in the number of cattle euthanized in the field.[8] In a survey[12] of 19 abattoirs and 3 auction markets in Canada, it was estimated that of the nonambulatory cattle that arrived at those facilities, < 1% (74/7,382) became debilitated during transit, which suggests that most cattle become nonambulatory on the farm. Although it is important to educate cattle producers on methods to prevent and care for nonambulatory cattle, it is equally important to provide them with evidence-based recommendations for proper equipment and procedures for euthanasia of such cattle when necessary.

The use of firearms for euthanasia of cattle is practical because nearly every cattle operation has access to firearms directly (owner or manager) or indirectly (employees or neighbors). However, published research regarding which firearms and ammunitions are appropriate for euthanasia of cattle is lacking, and replication and statistical analyses are limited in the research that is available. Moreover, imaging methods for the heads of cattle have improved such that in situ evaluation of the cranial cavity, brain, and projectile location following a gunshot can be performed. The purpose of the study reported here was to determine, by the use of CT, the efficacy of various combinations of commonly available firearms and ammunitions to penetrate and disrupt the brain tissue of cadaveric heads of feedlot steers.

Materials and Methods

Animals—Fresh cadaveric heads (n = 42) of 12- to 18-month-old *Bos taurus* beef feedlot steers were obtained from a kosher-kill abattoir to ensure that no preexisting skull or brain trauma would be present to confound evaluation of the CT images following application of the gunshot. Institutional animal care and use committee approval was not necessary for the study because no live animals were used. However, because of the sensitive nature of the subject matter, study approval was obtained from the administration of the Kansas State University Veterinary Teaching Hospital. Prior to study initiation, all firearm operators were trained and certified in a firearms safety program.

Study design—On the basis of order of procurement, each head was assigned a sequential number, to which 1 of 7 firearm-ammunition combinations (semiautomatic .22-caliber rimfire rifle[b] firing a .22-caliber long rifle 30-grain plated lead solid-point[c] or hollow-point[c] cartridge, semiautomatic .223-caliber carbine[d] firing a .223 caliber 50-grain ballistic-tip bullet,[e] semiautomatic 9-mm pistol[f] firing a 9-mm 124-grain total metal jacket round,[g] semiautomatic .45-caliber ACP[h] firing a .45 caliber 230-grain full metal jacket round,[i] and a pump-action 12-gauge shotgun[j] firing a 12-gauge 2.75-inch 1.25-ounce No. 4 birdshot shell[k] or a 1-ounce rifled slug[l]) had been randomly assigned by use of a random-number generator[m] a priori such that each firearm-ammunition combination was applied to 6 heads. All firearms were owned by study personnel, and standard factory-loaded ammunitions were used.

The KE generated by the projectile for each firearm-ammunition combination was calculated by use of the equation,[5] $KE = mv^2/2$, where m is the mass of the projectile in kilograms and v is the muzzle velocity of that combination (ie, the instantaneous speed of the projectile when it leaves the muzzle of the gun) in meters per second. For each firearm-ammunition combination, the projectile was shot across a chronograph[n] 3 times to determine the mean muzzle velocity for that combination. Then, the projectiles were manually separated from the casing and weighed to obtain the mean mass for that given ammunition.

Each head was placed in a custom-made stanchion to ensure that the longitudinal axis of the projectile impacted the frontal bone at an 85° to 90° angle. That angle range reflects the proper and practically achievable angle for the projectile to impact the frontal bone in recumbent or restrained animals, and efforts should be made to maintain that angle regardless of whether the animal is standing or recumbent to ensure proper targeting of the brain and brainstem and minimize the risk that the projectile ricochets. Each head was shot only once with the assigned firearm-ammunition combination from a distance of 3 m, and the target for the impact point was the intersection of 2 lines, each drawn from the medial canthus of 1 eye to the base of the contralateral ear at an angle directed toward the greater foramen of the occipital bone as described.[13] Following each gunshot, the head and its immediate area were searched for evidence that the projectile had exited the head. The heads were then transported to the Kansas

Table 1—Calculated KE for each of 7 firearm-ammunition combinations that were evaluated to determine their efficacy for the euthanasia of 12- to 18-month-old feedlot cattle.

Firearm	Ammunition	KE (J)
Semiautomatic .22-caliber rimfire rifle[b]	.22-caliber long rifle 30-grain plated lead solid-point cartridge[c]	216.80
	.22-caliber long rifle 30-grain plated lead hollow-point cartridge[c]	218.74
Semiautomatic .223-caliber carbine[d]	.223-caliber 50-grain ballistic tip bullet[e]	1,604.38
Semiautomatic 9-mm pistol[f]	9-mm 124-grain total metal jacket round[g]	427.85
Semiautomatic .45-caliber ACP[h]	.45-caliber ACP 230-grain full metal jacket round[i]	747.16
Pump-action 12-gauge shotgun[j]	12-gauge 2.75-inch 1.25-ounce No. 4 birdshot shell[k]	2,398.32
	12-gauge 2.75-inch 1-ounce rifled slug[l]	5,552.28

Kinetic energy was calculated by use of the following equation: $KE = mv^2/2$, where m is the mean mass of the projectile in kilograms and v is the mean muzzle velocity of the firearm (ie, the instantaneous speed of the projectile when it leaves the muzzle of the gun) in meters per second. For each firearm-ammunition combination, the projectile was shot across a chronograph 3 times to determine the mean muzzle velocity for that combination. Then, the projectiles were manually separated from the casing and weighed to obtain the mean mass for that given ammunition.

State University Veterinary Teaching Hospital for CT evaluation.

Computed tomographic evaluation was performed with a third-generation scanner[o]; serial coronal images were obtained at 3-mm intervals and a reconstruction interval of 1.5 mm. The images were sequentially numbered to ensure that the radiologist who evaluated them remained unaware of the assigned firearm-ammunition combination and were stored in an electronic medical database. The radiologist accessed the images through the database and used a standardized worksheet to record measurements of extent of projectile integrity, fragmentation, and penetration; brain tissue destruction; and brainstem involvement. The radiologist also recorded whether the injury would have resulted in instantaneous death, which was defined as ≥ 30% destruction of brain tissue or a brainstem lesion.

Statistical analysis—Given the small number (n = 6) of replications for each firearm-ammunition combination, descriptive statistics were generated and reported. The depth of penetration by the projectile into the cranial cavity was compared among the firearm-ammunition combinations by use of a general linear model. Least squared means are reported with Tukey-adjusted *P* values to account for multiple pairwise comparisons. All analyses were performed with software,[p] and values of $P < 0.05$ were considered significant.

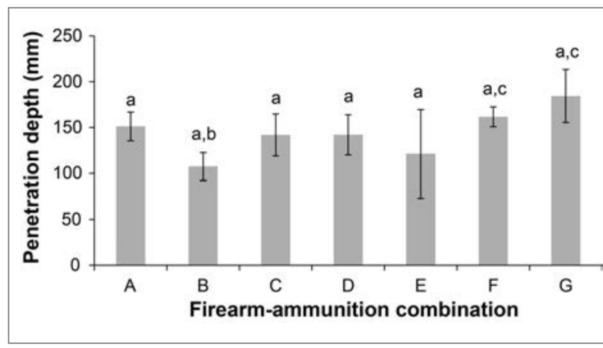

Figure 1—Mean ± SD depth of penetration of the projectile into the cranial cavity following application of a gunshot to cadaveric heads (n = 42) of 12- to 18-month-old beef feedlot cattle as determined by evaluation of CT images for each of 7 firearm-ammunition combinations (semiautomatic .22-caliber rimfire rifle[b] firing a .22-caliber long rifle 30-grain plated lead solid-point[c] [A] or hollow-point[c] [B] round, semiautomatic .223-caliber carbine[d] firing a .223 caliber 50-grain ballistic-tip round[e] [C], semiautomatic 9-mm pistol[f] firing a 124-grain total metal jacket round[g] [D], semiautomatic .45-caliber ACP[h] firing a 230-grain full metal jacket round[i] [E], and pump-action 12-gauge shotgun[j] firing a 2.75-inch No. 4 birdshot shell[k] [F] or a 1-ounce rifled slug[l] [G]) that were assessed to determine their efficacy for euthanasia. Each firearm-ammunition combination was applied from a distance of 3 m to 6 fresh cadaveric heads that were obtained from a kosher-kill abattoir. Heads were positioned in a custom-made stanchion such that the longitudinal axis of the projectile impacted the frontal bone at an 85° to 90° angle to ensure proper targeting of the brain and brainstem and minimize the risk of the projectile ricocheting. [a–c]Means with different letters vary significantly ($P < 0.05$).

Results

The calculated KE generated by the projectile for each firearm-ammunition combination was summarized **(Table 1)**. The skull was penetrated by the projectile in 41 of 42 cadaveric heads, and the mean ± SD depth of penetration by the projectile into the cranial cavity for each firearm-ammunition combination was summarized **(Figure 1)**. The mean depth of penetration for the .22-caliber hollow-point cartridge fired by a .22-caliber rifle was significantly ($P < 0.05$) less, compared with the depth of penetration for the No. 4 birdshot shell and 1-ounce rifled slug fired by the 12-gauge shotgun, but did not differ significantly from the depth of penetration for the other 4 firearm-ammunition combinations assessed. For 4 of the 7 firearm-ammunition combinations (.22-caliber rifle firing a .22-caliber hollow-point cartridge, .223-caliber carbine firing a .223-caliber 50-grain ballistic-tip bullet, 12-gauge shotgun firing a No. 4 birdshot shell, and 12-gauge shotgun firing a 1-ounce rifled slug), the projectile fragmented on entry into the cranial cavity during every application **(Table 2)**. The number of skulls that had fractures other than the entry point of the projectile varied among firearm-ammunition combinations. None of the heads shot with the .22-caliber rifle and .22-caliber solid-point cartridge had additional skull fractures; however, the presence of additional skull fractures was not indicative of the ability of a round to cause instantaneous death (≥ 30% destruction of brain tissue or brainstem lesion). Of the 7 firearm-ammunition combinations, the .22-caliber rifle firing a .22-caliber solid-point cartridge and the 12-gauge shotgun firing a No. 4 birdshot shell or a 1-ounce rifled slug were the combinations that most frequently caused brainstem lesions and trauma sufficient to cause instantaneous death. In fact, the 12-gauge shotgun firing a 1-ounce rifled slug was

Table 2—Number of projectiles that fragmented at entry into the cranial cavity and cadaveric heads with skull fractures in addition to the entry point of the projectile, brainstem lesions, and sufficient trauma to result in instantaneous death (≥ 30% destruction of brain tissue or brainstem lesion) for each of the 7 firearm-ammunition combinations of Table 1.

Firearm	Ammunition	Fragmented projectiles	Additional skull fractures	Brainstem lesions	Instantaneous death
Semiautomatic .22-caliber rimfire rifle	.22-caliber long rifle 30-grain plated lead solid-point cartridge	5	0	4	5
	.22-caliber long rifle 30-grain plated lead hollow-point cartridge	6	1	2	3
Semiautomatic .223-caliber carbine	.223-caliber 50-grain ballistic-tip bullet	6	2	5	5
Semiautomatic 9-mm pistol	9-mm 124-grain total metal jacket round	2	3	2	2
Semiautomatic .45-caliber ACP	.45-caliber ACP 230-grain full metal jacket round	3	5	2	4
Pump-action 12-gauge shotgun	12-gauge 2.75-inch 1.25-ounce No. 4 birdshot shell	6	1	4	5
	12-gauge 2.75-inch 1-ounce rifled slug	6	6	5	6

Each firearm-ammunition combination was applied from a distance of 3 m to 6 fresh cadaveric heads that were obtained from a kosher-kill abattoir. Heads were positioned in a custom-made stanchion such that the longitudinal axis of the projectile impacted the frontal bone at an 85° to 90° angle to ensure proper targeting of the brain and brainstem and minimize the risk of the projectile ricocheting.

See Table 1 for remainder of key.

the only combination evaluated for which all 6 heads to which it was applied had sufficient trauma to the brain and brainstem that instantaneous death was the expected consequence. The 9-mm pistol firing a 9-mm total metal jacket round was the combination that caused the least amount of brain tissue or brainstem trauma; only 2 of the 6 heads shot with that combination had sufficient trauma to result in instantaneous death.

Representative midsagittal CT images from each firearm-ammunition combination were selected (**Figure 2**). Gross differences in the depth of penetration by the projectile, projectile and skull fragmentation, and brain matter destruction were observed among the firearm-ammunition combinations. The head shot with the 9-mm pistol and 9-mm total metal jacket round had a small entry wound in the frontal bone and minimal fragmentation of the projectile, additional skull fractures, and destruction of brain tissue. The head shot with the .22-caliber rifle and a .22-caliber solid-point cartridge had little damage to the frontal bone and no additional skull fractures, and although abundant brain tissue was still present, the path of the projectile was littered with multiple metallic fragments. Conversely, the head shot with the 12-gauge shotgun and 1-ounce rifled slug had a large entry wound in the frontal bone, multiple additional skull fractures, and extensive destruction and caudal displacement of brain tissue.

Discussion

To our knowledge, the present study was the first to compare the efficacy of several commonly available firearm-ammunition combinations for the euthanasia of yearling beef feedlot cattle. Results indicated substantial variability in the depth of projectile penetration into the cranial cavity, amount of projectile fragmentation, and extent of skull fracture, brain tissue destruction, and brainstem lesions among the 7 firearm-ammunition combinations evaluated. Those objective outcomes as well as cost, availability, and reliability of equipment (ie, firearm and ammunition); restraint of the animal; operator experience; distance between the operator and animal; potential for operator fatigue; and risk of harm to observers, other cattle, and the surrounding environment need to be considered when a method is chosen for euthanasia of individual cattle or mass depopulation of a cattle operation because of a catastrophic infectious or foreign animal disease outbreak.

The authors[14] of a detailed review of bullets and their flight characteristics (ie, ballistics) and wounding mechanisms suggest that there are 2 major mechanisms by which bullets cause trauma. One mechanism is the crushing of tissue as it is struck by the bullet and the formation of a permanent cavity. The other mechanism is the radial stretching of tissue as the bullet passes, which forms a temporary cavity. Other considerations that factor into the wounding mechanisms of gunshots are the KE generated by the firearm-ammunition combination and the amount of projectile fragmentation that occurs when it impacts the target.

Results of a study[5] indicate that a projectile with 127 J of KE is sufficient to penetrate the frontal bone of a 3-year-old Angus cow. On the basis of that value as a guideline, all of the firearm-ammunition combinations evaluated in the present study yielded sufficient KE to penetrate the frontal bone of yearling feedlot steer, assuming that the frontal bone of yearling feedlot steer is similar to that of a 3-year-old Angus cow. However, a ballistic measurement such as KE does not necessarily correlate with efficacy of euthanasia. For example, in the present study, the KEs for the combinations in which a .22-caliber rifle was used to fire either a solid- or hollow-point cartridge were similar, yet the hollow-point cartridge was inferior to the solid-point cartridge for euthanasia of cattle on the basis of extent of brain tissue destruction and brainstem lesions. Thus, no single measure can be used to determine the killing or traumatic potential of a given firearm-ammunition combination; instead factors such as thickness or density of the target tissue, point in the path of a projectile at which yaw or fragmentation occurs, and inherent projectile characteristics such as metal composition and jacketing should be considered.[14]

Differences among the firearm-ammunition combinations evaluated in this study were evident during evaluation of the CT images. The rounds fired by the 9-mm pistol and .45-caliber ACP did not fragment as much as the other rounds upon impact with the frontal bone. This was most likely because of the properties of those respective projectiles rather than a function of

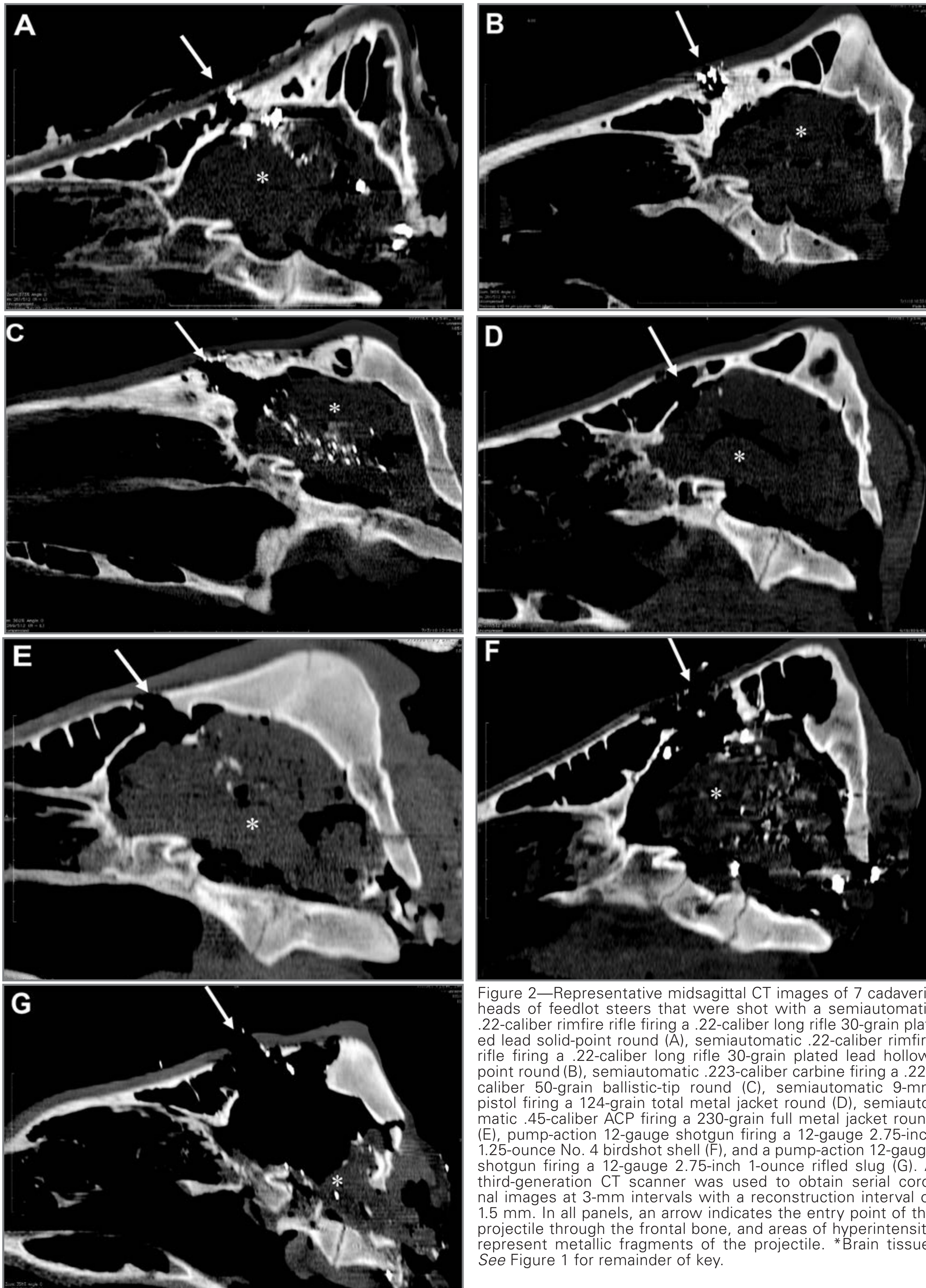

Figure 2—Representative midsagittal CT images of 7 cadaveric heads of feedlot steers that were shot with a semiautomatic .22-caliber rimfire rifle firing a .22-caliber long rifle 30-grain plated lead solid-point round (A), semiautomatic .22-caliber rimfire rifle firing a .22-caliber long rifle 30-grain plated lead hollow-point round (B), semiautomatic .223-caliber carbine firing a .223 caliber 50-grain ballistic-tip round (C), semiautomatic 9-mm pistol firing a 124-grain total metal jacket round (D), semiautomatic .45-caliber ACP firing a 230-grain full metal jacket round (E), pump-action 12-gauge shotgun firing a 12-gauge 2.75-inch 1.25-ounce No. 4 birdshot shell (F), and a pump-action 12-gauge shotgun firing a 12-gauge 2.75-inch 1-ounce rifled slug (G). A third-generation CT scanner was used to obtain serial coronal images at 3-mm intervals with a reconstruction interval of 1.5 mm. In all panels, an arrow indicates the entry point of the projectile through the frontal bone, and areas of hyperintensity represent metallic fragments of the projectile. *Brain tissue. *See* Figure 1 for remainder of key.

the caliber or type of firearm used to fire them. Both projectiles were metal jacketed (copper) and were designed to maintain their shape upon impact so as to achieve a greater depth of penetration, compared with that of soft- or hollow-point projectiles, which tend to fragment or mushroom upon impact. Metal-jacketed ammunition is often used with autofeeding-type handguns (eg, the 9-mm pistol and .45-caliber ACP used in the present study) to maintain the depth of penetration of the projectile because of the lower muzzle velocity and KE, compared with that of cartridges commonly fired from rifles.

Comparison of the CT images of the heads shot with the .22-caliber rifle and .22-caliber solid-point cartridges with those of heads shot with the same rifle and .22 hollow-point cartridges provided an example of the effect that a projectile's composition has on its behavior after impact. Among the 7 firearm-ammunition combinations evaluated, the depth of penetration into the cranial cavity by the .22-caliber hollow-point cartridge fired by the .22-caliber rifle was the least, and the depth of penetration for the .22-caliber hollow-point cartridge was approximately 55 mm less than that for the .22-caliber solid-point cartridge, despite the fact that the 2 cartridges were fired by the same rifle and the KEs for both combinations were similar. This finding was expected because hollow-point projectiles are designed for maximum expansion and fragmentation upon impact[15]; however, that characteristic makes hollow-point projectiles undesirable for euthanasia of cattle because of the thickness and density of the bovine frontal bone. When a projectile strikes the frontal bone, it expends a large amount of its KE and thus loses some of its wounding potential.[14] If the projectile fragments upon impact, even more KE is lost, and its wounding potential is decreased further. In the present study, the .22-caliber hollow-point cartridge fragmented upon impact with the frontal bone and frequently lacked sufficient KE to cause substantial damage to the brain or brainstem. In fact, of the 6 heads that were shot with the .22-caliber hollow-point cartridge, 2 had brainstem lesions, and only 3 had sufficient brain or brainstem damage to result in instantaneous death.

Similar to the .22-caliber hollow-point cartridges, the .223-caliber ballistic-tip bullets fired by the .223-caliber carbine also fragmented upon impact with the frontal bone. However, the KE for that firearm-ammunition combination was approximately 6 times as great as that for the .22-caliber rifle and .22-caliber hollow-point cartridge; thus, the amount of brain tissue destruction caused by the .223-caliber ballistic-tip bullet was substantially greater than that caused by the .22-caliber hollow-point cartridge. Moreover, despite the small diameter and mass of the .223-caliber ballistic-tip bullet, the extent of its fragmentation at impact increased the amount of brain tissue subjected to crushing injury, and brainstem lesions (ie, instantaneous death) occurred in 5 of 6 heads evaluated.

For one of the heads shot with the .45-caliber ACP and .45-caliber ACP full metal jacket round combination, the projectile exited the foramen magnum; however, it did not have enough KE to penetrate a thin piece of plastic that was mounted behind the head. The probability that the projectile would have exited an intact animal was low because it is likely the projectile would have become trapped within either the cervical spinal column or the adjacent muscles. Regardless, when firearms are used for the euthanasia of cattle, there is always a risk that the projectile will pass through or ricochet from the intended target, and this risk should be carefully considered when decisions are made about when and where euthanasia by firearm should be performed.

Ballistics, even in controlled studies, often leads to debate and is fraught with many misconceptions. Consequently, various ballistics and trauma experts have written reports[16,17] to elucidate their personal views of ballistics. Most of the studies that have been conducted to evaluate ballistics, behavior of projectiles in tissue, and killing potential have been case-series reports that describe wounds to soft tissues or involved the use of ballistics gelatin, which is designed to closely resemble the physical properties of muscle tissue.[18] This is most likely because those studies were performed for military or forensic purposes, in which the center of mass (ie, body) is the usual target. For euthanasia of cattle, the brain should always be the target; therefore, consultation of the literature for recommendations regarding projectile selection should be done with caution, and studies that did not consider projectile penetration of thick bone should be avoided.

Results of the present study indicated that a 9-mm pistol firing a 9-mm 124-grain total metal jacket round and a .22-caliber rifle firing a .22-caliber hollow-point cartridge were poor choices for the euthanasia of 12- to 18-month old beef feedlot steers because instantaneous death (≥ 30% destruction of brain tissue or brainstem lesion) was a predicted consequence for only 2 of 6 and 3 of 6 heads evaluated, respectively. Conversely, the other firearm-ammunition combinations evaluated appeared to be viable options for the euthanasia of feedlot cattle. These findings should be interpreted with caution because the purpose of this study was not to identify the best firearm-ammunition combination that will result in successful euthanasia of feedlot cattle in all situations. Rather, this study was intended as a preliminary investigation of commonly available firearm-ammunition combinations that might be considered for the euthanasia of feedlot cattle, and these findings should be applicable for occasional on-farm euthanasia of individual cattle. However, further research is necessary to determine the best method for depopulation of large numbers of cattle in the event of a catastrophic infectious or foreign animal disease outbreak, and factors such as firearm and ammunition availability, operator fatigue, animal restraint, distance required between operator and animal, cost, safety, and the practicality of achieving a humane death for all animals in such a situation should be considered.

---

a. Rooney JA. Response to an FMD outbreak: use of vaccination in control strategies (oral presentation). 4th Annu Cross Border Livest Health Conf, Portland, Ore, July 2011. Available at: www.cblhconference.com/pdf/2011-pres-Response-FMD-outbreak.pdf. Accessed Jun 27, 2013.
b. Marlin Model 60, Marlin Firearms Co, Madison, NC.
c. Aguila Super Maximum, Centurion Ordnance Inc, Helotes, Tex.
d. Bushmaster M4A3 Type Carbine, Bushmaster Firearms International, Madison, NC.

e. Hornady V-Max, Hornady Manufacturing Co, Grand Island, Nev.
f. Ruger P-89, Sturm, Ruger & Co Inc, Newport, NH.
g. Lawman Ammunition, Ammunition Accessories Inc, Lewiston, Ind.
h. M1911A1, Springfield Armory, Geneseo, Ill.
i. .45 ACP, Federal Cartridge Co, Anoka, Minn.
j. Remington 870 Wingmaster, Remington Arms Co, Madison, NC.
k. Federal Heavy Field Load, Federal Cartridge Co, Anoka, Minn.
l. Winchester Super-X Power Point, Winchester, East Alton, Ill.
m. Excel 2007, Microsoft Corp, Redmond, Wash.
n. Shooting Chrony Inc., Mississauga, ON, Canada.
o. General Electric CTI, GE Medical Systems, Milwaukee, Wis.
p. SAS, version 9.2, SAS Institute Inc, Cary, NC.

References

1. Nusbaum KE, Wenzel JG, Everly GS Jr. Psychologic first aid and veterinarians in rural communities undergoing livestock depopulation. *J Am Vet Med Assoc* 2007;231:692–694.
2. AVMA Panel on Euthanasia. *AVMA guidelines for the euthanasia of animals: 2013 edition*. Schaumburg, Ill: AVMA, 2013. Available at: www.avma.org/KB/Policies/Documents/euthanasia.pdf. Accessed Sept 9, 2013.
3. AVMA Panel on Euthanasia. 2000 report of the AVMA Panel on Euthanasia. *J Am Vet Med Assoc* 2001;218:669–696.
4. American Association of Bovine Practitioners Animal Welfare Committee. Practical euthanasia of cattle: considerations for the producer, livestock market operator, livestock transporter, and veterinarian. Available at: www.aabp.org/resources/euth.asp. Accessed Jan 28, 2009.
5. Blackmore DK. Energy requirements for the penetration of heads of domestic stock and the development of a multiple projectile. *Vet Rec* 1985;116:36–40.
6. 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.
7. Finnie JW. Neuroradiological aspects of experimental traumatic missile injury in sheep. *N Z Vet J* 1994;42:54–57.
8. USDA Food Safety and Inspection Service. Disposition of nonambulatory disabled cattle. Available at: www.fsis.usda.gov/OPPDE/rdad/FSISNotices/09-13.pdf. Accessed Jun 26, 2013.
9. Blackmore DK, Bowling MC, Madié P, et al. The use of a shotgun for the emergency slaughter or euthanasia of large mature pigs. *N Z Vet J* 1995;43:134–137.
10. Kobayashi M, Carpenter TE, Dickey BF, et al. A dynamic, optimal disease control model for foot-and-mouth-disease: II. Model results and policy implications. *Prev Vet Med* 2007;79:274–286.
11. Stull CL, Payne MA, Berry SL, et al. A review of the causes, prevention, and welfare of nonambulatory cattle. *J Am Vet Med Assoc* 2007;231:227–234.
12. Doonan G, Appelt M, Corbin A. Nonambulatory livestock transport: the need of consensus. *Can Vet J* 2003;44:667–672.
13. Shearer J, Nicoletti P. Procedures for humane euthanasia of livestock. Available at: www.neacha.org/resources/Humane.livestock.Euthanasia.pdf. Accessed Jun 26, 2013.
14. Hollerman JJ, Fackler ML, Coldwell DM, et al. Gunshot wounds: 1. Bullets, ballistics, and mechanisms of injury. *AJR Am J Roentgenol* 1990;155:685–690.
15. Di Maio VJM. *Gunshot wounds: practical aspects of firearms, ballistics, and forensic techniques*. 2nd ed. Boca Raton, Fla: CRC Press Inc, 1999;26–27.
16. Lindsey D. The idolatry of velocity, or lies, damn lies, and ballistics. *J Trauma* 1980;20:1068–1069.
17. Fackler ML. *What's wrong with the wound ballistics literature, and why*. Institute report No. 239. San Francisco: Letterman Army Institute of Research, Division of Military Trauma Research, 1987.
18. Fackler ML. Physics of missile injuries. In: McSwain NE Jr, Kerstein MD, eds. *Evaluation and management of trauma.* Norwalk, Conn: Appleton-Century-Crofts, 1987;25–41.