Quantitative assessment of bullet fragments in viscera of sheep carcasses as surrogates for white-tailed deer

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Abstract: Avian scavengers, such as bald eagles (*Haliaeetus leucocephalus*), can be exposed to lead through the consumption of spent lead from ammunition in carcasses of animals shot with lead-based projectiles. Few studies have examined the degree of bullet fragmentation in viscera (offal) of game mammals. Our objective was to quantify the number of bullet fragments deposited in sheep carcasses shot with different types of lead and lead-free, high-velocity centerfire rifle bullets and with lead projectiles fired from shotguns and muzzleloader rifles marketed for hunting white-tailed deer (*Odocoileus virginianus*). We hypothesized that after controlling for velocity, angle of entry, distance from target, and shot placement (thoracic region), most of the bullet fragments would be deposited in the impact zone (heart and lungs). After radiographic examination of all viscera from each carcass, we detected metal fragments in 96% of the viscera and found that metal fragments were deposited in greater quantities in the abdominal viscera (organs caudal to the diaphragm) compared to the thoracic viscera (heart and lungs). Additionally, bullets fired from the centerfire rifle fragmented more than the projectiles fired from the shotgun and muzzleloader rifle. Rapid-expansion lead bullets fragmented more than controlled-expansion lead bullets and lead-free bullets. However, 1 type of controlled-expansion bullet that is comprised almost entirely of lead and advertised to retain >90% of its weight, fragmented similarly to the rapid expansion lead bullets. We observed lead fragments produced by centerfire rifle bullets and shotgun and muzzleloader projectiles present in sheep carcasses and conclude that lead is made available to scavengers from the distribution of lead fragments lodged in the carcasses of game through viscera left in the field by hunters. To eliminate this type of lead exposure, shooters must employ the use of lead-free projectiles or completely remove the remains of shot animals from the field.

Key words: avian scavengers, bullet fragments, deer hunting, human–wildlife conflicts, lead exposure, lead-free bullets, offal piles

TRADITIONALLY, LEAD has been the metal of choice for manufacturing ammunition because it is inexpensive, relatively abundant, malleable, and dense enough to produce effective and lethal bullets (Oltrogge 2009). In addition, the ballistics of lead-based ammunition are well-understood (Caudell 2013). High-velocity, copper-jacketed, lead-core bullets are the most commonly used type of bullets for hunting big game with modern centerfire rifles; these bullets are available in a wide range of calibers and grains (weights; Kneubuehl et al. 2011, Caudell et al. 2012). Shotguns and muzzleloader rifles also are used for hunting big game, and these firearms use either a single, heavy projectile or large pellets (Kneubuehl et al. 2011).

The shape and composition of a bullet will dictate its behavior upon hitting the target, that is, whether it will fragment, deform (also referred to as mushrooming) or retain its shape and mass (dimensionally stable design; Caudell 2013, Trinogga et al. 2013, Gremse et al. 2014). Other factors that will affect a bullet's behavior upon impact include distance, terminal velocity, angle of entry, and the characteristics of the tissue impacted (Kneubuehl et al. 2011, Caudell 2013, Gremse et al. 2014).

Lead-based bullets (some designed to expand rapidly and others designed to fragment upon impact) used for hunting and recreational shooting are a source of lead exposure in wildlife, because scavengers can ingest lead ammunition residues from ingesting shot animals or their parts that are left in the field (Hunt et al. 2006, Haig et al. 2014). An association between exposure to lead from

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Table 1. Description of the different firearms and bullet types, bullet weight, retained bullet weight, projectile velocities (in meters/second) used to shoot sheep carcasses (as surrogates for white-tailed deer) controlling for distance (50 m), angle of entry (perpendicular to the shooter), and shot placement (thoracic region).[a]

Firearm	Bullet type	Manufacturer	Brand name	Velocity in ft/s (mean ± SE)	Retained bullet weight (%)	Number of fragments in viscera[b] (mean ± SE)
Centerfire rifle (.308 [7.62mm] caliber Winchester)	Rapid expansion (RE1)	Nosler	Ballistic tip	2874 ± 10.8 A	48.2 A	481 ± 83.7 A
	Rapid expansion (RE2)	Remington	Core-Lokt	2903 ± 17.3 A	48.4 A	280 ± 52.1 B
	Controlled expansion (CE1)	Winchester	XP³	2805 ± 12.5 A	91.1 B	35 ± 15.4 C
	Controlled expansion (CE2)	Hornady	Interbond	2933 ± 22.3 A	76.3 C	346 ± 498 D
	Lead-free	Barns	TSX	2854 ± 33.1	96.4 B	25 ± 7.2 B
Shotgun (12 gauge)	Slug	Remington	Foster slug	1482 ± 39.6 B	96.3 B	38 ± 11.3 B
Muzzleloader rifle (.50 caliber)	MZ1	Powerbelt	Aero Tip	1558 ± 21.3 B	97.3 B	13 ± 4.4 B
	MZ2	Hornady	XTP	1587 ± 4.2 B	90.8 B	36 ± 5.4 B

[a] All carcasses were shot by the same shooter and the bullets' velocities were measured with a chronograph placed 3 m away from the shooter.
[b] Thoracic and abdominal viscera combined. Different letters denote statistical significance between bullet types ($P < 0.05$).

ammunition and elevated lead levels in avian scavengers has been reported for California condors (*Gymnogyps californianus*; Church et al. 2006, Hunt et al. 2006), bald eagles (*Haliaeetus leucocephalus*; Cruz-Martinez et al. 2012, Bedrosian et al. 2012, Warner et al. 2014), white-tailed sea eagles (*H. albicilla*; Krone et al. 2009), and Steller's sea eagles (*H. pelagicus*; Saito 2000).

Few studies have assessed bullet fragmentation and deposition in both carcasses and viscera (offal) of shot game, and such studies have been conducted under normal hunting conditions (Hunt et al. 2006, Knott et al. 2009), in which many of the variables contributing to bullet fragmentation (i.e., angle of bullet entry, shot placement, distance from target, and firearm and bullet types) cannot be or were not controlled.

Because of the concerns about lead exposure both for humans who may consume wild game harvested with lead bullets and wildlife exposed to lead in the carsasses left by hunters, we collaborated with the Minnesota Department of Natural Resources to provide guidance to hunters for reducing the risk of lead exposure for themselves (Grund et al. 2010) and wildlife. In this study we evaluated categories of firearms and ammunition types for deer-hunting, controlling shot placement, velocity, angle of entry, and distance from target.

We predicted that upon a lethal shot (bullet impact on the heart and lungs), bullet fragments would concentrate more in the thoracic viscera (lungs and heart). This study, therefore, was a quantitative assessment of bullet fragment deposition within the viscera of animal carcasses shot in the thoracic region using different types of firearms and ammunition.

Methods

In July 2008, we purchased 72 euthanized domestic sheep (*Ovis aries*) carcasses from a local slaughterhouse to be used as surrogates for white-tailed deer because of their comparable anatomy and dimensions. Following methodology described in Grund et
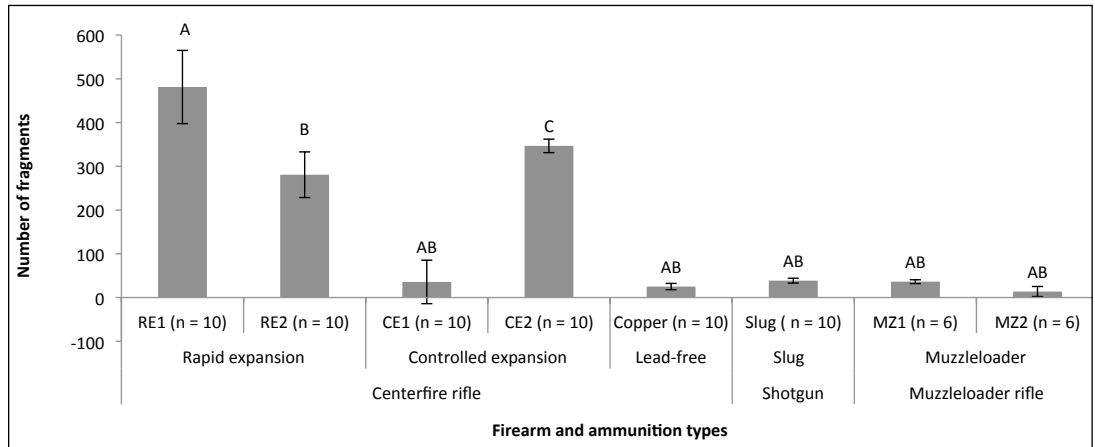
Figure 1. Average number of metal fragments observed in viscera by ammunition types.

al. (2010), we suspended each carcass in a sternal recumbent position in a wooden frame, marked them for identification, and, for consistent shot placement, drew a target using spray paint at the accepted vital shot location (Grund et al. 2010). All carcasses were shot in the thoracic region by the same shooter on the same day, avoiding the scapula, from a distance of 50 m. We recorded the projectiles' velocity with a chronograph set up 3 m from the shooter.

We used 3 types of firearms with 5 types of ammunition (Table 1). The first type of firearm was a .308 caliber Winchester centerfire rifle. We used 2 brands of lead-based bullets designed to expand rapidly on impact (hereafter, rapid-expansion bullets; RE1 and RE2); 2 brands of lead-based bullets designed to retain their shape and, therefore, resist fragmentation (hereafter, controlled-expansion bullets; CE1 and CE2); and 1 brand of lead-free bullets made entirely of copper. All bullets were 150 grains. We shot 10 carcasses using each bullet type for each of the 5 centerfire rifle bullets tested. The second type of firearm was a .50 caliber muzzleloader rifle firing 245 grain (MZ1) and 300 grain (MZ2) lead bullets; we shot 12 carcasses (six using each bullet type). The third type of firearm used was a 12-gauge shotgun with a 1-ounce lead slug with which we shot 10 carcasses.

On the same day of the shooting, we skinned and eviscerated the carcasses following standard field dressing techniques at the University of Minnesota's Veterinary Diagnostic laboratory. We separated the heart and lungs from the remaining organs caudal to the diaphragm

(abdominal viscera) and placed them in plastic bags. At the Raptor Center at the University of Minnesota, we radiographed the viscera using a C325 S Bennett X-ray machine (Bennett X-ray Corp. Copiague, N.Y.). We placed each bag of viscera in a plastic tray on top of a 35- x 43-cm, green light-emitting, rare-earth screen cassette (3M Asymetrix ™ Fast Detail, 3M Animal Care Products, St. Paul, Minn.). We set the exposure at 48 kilovolt peak (kvp), 200 milliampere (mA) and 0.03 sec for the abdominal viscera; the kvp was adjusted to 42 for the thoracic viscera. This technique provided sufficient contrast to easily visualize and differentiate metal fragments from dense anatomical structures (i.e., bones) or debris. We processed radiographic films using an automatic radiographic film developer (Mini-medical 90, AFP Imaging Corp., Elmford, N.Y.).

We counted the number of metal particles per radiograph using an overlaid transparent film with a 1 x 1-cm grid and evaluated each cell from left to right, recording counts with a hand counter. We recorded all metal fragments visible with unaided vision (>1 mm); however, we did not record their size. Data from the thoracic and abdominal viscera (hereafter, viscera) were combined for comparison of firearm and ammunition types and analyzed separately. We compared the mean number of fragments produced among the different types of firearms and among the different types of bullets using ANOVA procedures with post hoc Tukey's tests. In addition, we compared the mean number of bullet fragments from the
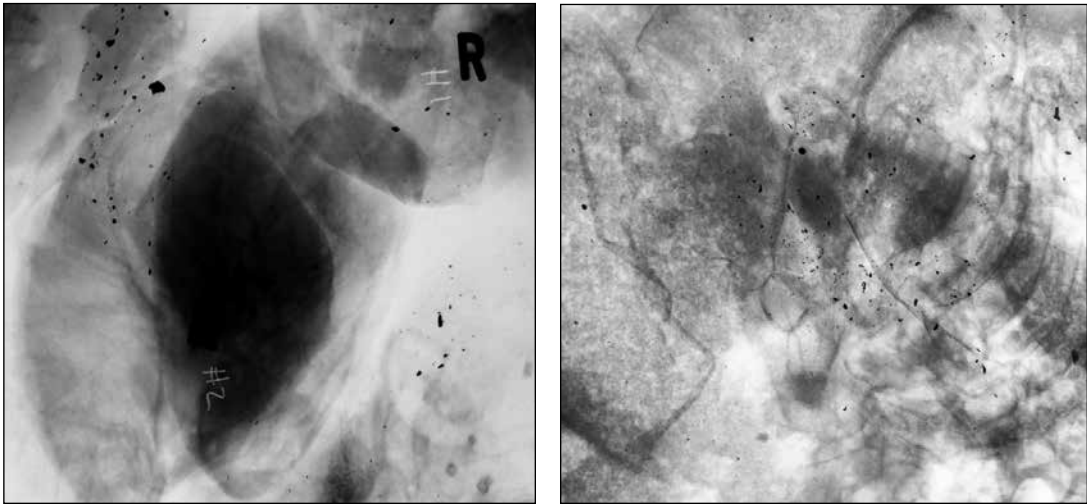
Figure 2. Radiograph of a sheep's viscera shot with a rapid-expansion (RE1) bullet showing retained metal fragments (black specks) in the thoracic viscera (heart and lungs; left) and in the abdominal viscera (right). For all types of firearms and ammunition the mean number of fragments was higher in the abdominal viscera (organs caudally to the diaphragm).

thoracic viscera to the abdominal viscera using ANOVA with post-hoc Tukey's tests. Alpha was set at 0.05 for all comparisons. We used Statistix 8.0 (Analytical Software, Tallahassee, Fla.) for the statistical analyses.

Results

We found that 96% (n = 69) of the carcasses shot had radiographic evidence of metal fragments in both the thoracic and abdominal viscera. The mean number of fragments retained in these viscera varied among the different types of bullets used ($F_{7,64}$ = 17.83, P < 0.0001;

Figure 1). The rapid-expansion bullets and a controlled-expansion bullet (CE2) deposited more fragments compared to the other controlled-expansion bullets (CE1), lead-free bullets, lead shotgun slugs, and muzzleloader slugs. No differences (P > 0.05) were detected among these latter 4 types of projectiles. No difference (P > 0.05) was found between the 2 brands of rapid-expansion bullets and the controlled-expansion bullet comprised mostly of lead (CE2). The 2 brands of controlled-expansion bullets fragmented differently (P < 0.05) with a higher number of fragments

Table 2. Mean (± SE) number of bullet fragments observed in radiographs of the thoracic viscera (heart and lungs) and abdominal viscera (organs caudal to the diaphragm) of shot sheep carcasses with 5 different types firearms and ammunition.[a]

Firearms	Bullet types	Thoracic viscera	Abdominal viscera	t (df)	P value
Centerfire rile	RE1	61 (9) A	420 (89) A	-3.7 (9)	0.005
	RE2	114 (18) B	165 (60) B	-0.6 (9)	0.5
	CE1	1 (0.6) C	34 (15) C	-2.1 (9)	0.06
	CE2	57 (20) D	289 (58) D	-3.2 (9)	0.01
	Lead-free	1 (0.3) C	24 (7) C	-3.2 (9)	0.01
Shotgun	Lead slug	23 (10) E	12 (7) C	0.6 (9)	0.5
Muzzleloader rifle	MZ1	1 (1.3) C	12 (4) C	-2.9 (5)	0.03
	MZ2	9 (3) E	26 (8) C	-1.5 (5)	0.17

[a]Carcasses were skinned and eviscerated and the cranial and caudal viscera were collected in separate plastic bags prior to radiographic evaluation. RE = rapid-expansion; CE = controlled-expansion; MZ = muzzleloader. Alpha caps denote statistical difference for the thoracic viscera and abdominal viscera colums (P < 0.05).

retained per viscera with CE2 compared to CE1. The least fragmentation and retention per viscera with center-fire ammunition occurred with CE1 controlled-expansion bullets and lead-free bullets. The velocity of the centerfire rifle bullets was similar for all bullet types ($F_{7,59}$ = 717.8 , $P < 0.0001$; Table 1), and the percentage of bullet weight retention differed among the bullet types ($F_{7,62}$ = 48.7, $P < 0.0001$; Table 1).

For the slower velocity firearm projectiles, we observed no differences ($P < 0.05$) in the number of metal fragments retained per viscera for the shotgun slug and the 2 types of muzzleloader bullets. These projectiles fragmented similarly to CE1 and lead-free bullets ($P < 0.05$).

The mean number of bullet fragments deposited in the thoracic and abdominal viscera varied among the bullet types. For the centerfire rifle bullets, greater bullet fragments were counted in the abdominal viscera (organs caudal to the diaphragm) compared to the thoracic viscera (cranial to the diagraph), except for RE2 and CE1 bullets (Table 2). The muzzleloader rifle bullets also deposited greater amount of fragments in the abdominal viscera (except for MZ2; Table 2). Although not statistically significant, we observed more lead slug fragments in the thoracic viscera (Table 2).

Discussion

We observed that almost all of the viscera from the shot carcasses presented radiographic evidence of bullet fragments after we controlled for several of the variables that determine how lead projectiles fragment upon impact, including velocity, distance from target, angle of entry, and shot placement. The fragments varied in size and shapes. Some were relatively large, while others were clusters of very fine particles, described as lead dust (Figures 2 and 3). Knott et al. (2009) suggested that the larger fragments seen in radiographs of ungulates shot with copper jacketed lead-core bullets derive from the jacket of copper. However, copper and lead are indistinguishable by radiography (Hollerman and Fackler 1995).

Similar to our findings, radiographic evidence of bullet fragments have been reported in viscera and carcasses of deer that were shot with commonly used hunting, lead-based bullets designed to expand rapidly upon impact (Hunt et al. 2006, Knott et al. 2009,
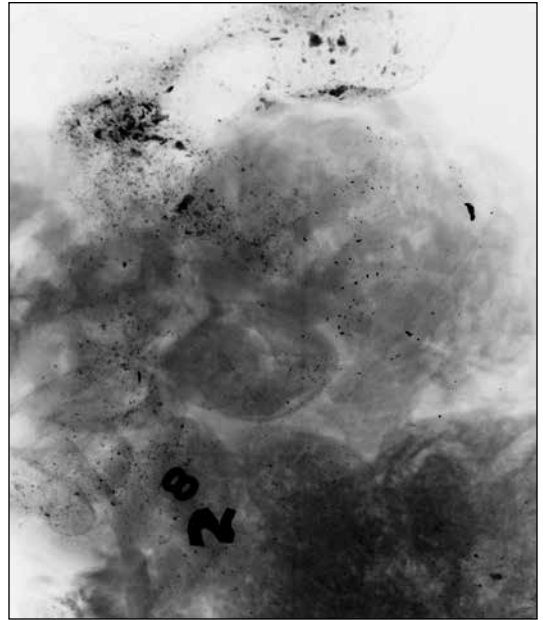
Figure 3. Radiograph of a sheep's viscera shot with a controlled-expansion (CE1) bullet. This type of bullet is comprised almost entirely of lead; and it fragmented similar to one of the types of rapid-expansion bullets (RE2).

Grund et al. 2010, Warner et al. 2014). Centerfire rifle bullets produced more fragments than shotgun and muzzleloader projectiles. This can be explained, at least in part, by the velocity of the projectiles (Hollerman and Fackler 1995). Consequently, projectiles traveling at faster speeds, as noted with those used in the present study (Table 1), produce more bullet fragments.

In addition to terminal velocity, bullet fragmentation depends on the projectile's design (Caudell et al. 2012). For example, rapid-expansion bullets are commonly used for hunting mid-sized game (Grund et al. 2010) and varmint animals (Knopper et al. 2006, Pauli and Buskirk 2007), because, upon impact, these bullets will deform at the tip (mushroom), increasing the bullet's surface area and, consequently, produce larger wound channels (Hollerman and Fackler 1995). These bullet types also yield many fragments that would contribute to the their wounding capacity (Caudell 2013). In contrast, the bullets for hunting large game, such as elk and moose, are designed to penetrate farther into the tissues controlling its expansion and deformation as they penetrate the tissues (Caudell et al. 2012, Caudell 2013). We found that the 2 types of

rapid-expansion bullets produced the greatest number of fragments, findings also observed in the carcasses of sheep evaluated by Grund et al. (2010).

We found that 1 type of controlled-expansion bullet, CE2 (manufactured to retain >90% of its weight), fragmented similarly to the 2 types of rapid-expansion bullets used in this study. A possible explanation could be that the lead core of CE2 bullets is bonded to the bullet's jacket, allowing greater exposure of the lead core upon impact, in contrast to the design of the CE1 bullets for which the lead core is enclosed with a copper jacket at the bottom of the bullet, thus, reducing exposure of the lead core (Grund et al. 2010). According to the manufacturer, the lead-free bullets used in the present study were made from copper and were designed to deform, but not fragment, so that the tip splits into several petals that curl back upon impact. Similar to our results, low numbers of metal fragments in tissue of game killed with 2 types of lead-free copper bullets have been reported (Hunt et al. 2006, Irschick et al. 2012). Both the lead slugs and muzzleloader bullets travel at slower velocities and are larger in size and mass compared to centerfire rifle bullets. The structural features of these projectiles allow them to deform slightly while retaining most of their weight, thereby producing large wounds (Hollerman and Fackler 1995, Gestring et al. 1996).

Bullet fragmentation also is determined by the characteristics of the tissue impacted. For example, elastic tissue, such as lungs, viscera, and muscle (Trinogga et al. 2013), pose less resistance to the projectile compared to bone (Kneubuehl et al. 2011, Caudell 2013). Consequently, greater bullet deformation and fragmentation will occur when a projectile strikes harder tissue. Therefore, we suggest that the fragmentation observed with the different types of projectiles used in this study was caused primarily by the projectiles' impacting the rib cage (avoiding the scapula) and, to a lesser degree, by the subsequent impact of the heart and lungs. Whereas the carcasses used in this study were fresh (not frozen and thawed), a bullet may behave differently compared to what would occur in a live animal (Caudell 2013).

Contrary to our hypothesis that a greater number of fragments would be deposited in the thoracic viscera (heart and lungs), we counted more metal fragments in the abdominal viscera of carcasses shot with centerfire rifle bullets and in a lesser degree with the muzzleloader bullets. This is probably due to a combination of factors, but, particularly to the velocity of centerfire rifle bullets that enable fragments to penetrate soft tissues at greater distances.

Studies report that fragments from fragmenting bullets can be found farther away (up to 45 cm) from the wound channel of shot sheep carcasses (Grund et al. 2010) and white-tailed deer (Stewart and Veverka 2012) than previously thought. In addition, Grund et al. (2010) reported that many bullet fragments were observed at the periphery of the radiographs of the shot sheep carcasses, suggesting that more fragments could have been present but that they were not able to quantify them. When deer were shot in the thoracic region with copper jacketed, lead-core bullets, the heart and lungs contained more fragments compared to the abdominal viscera (Knott et al. 2009). However, researchers used bullets of lesser weights (130 grains) and the culling was under field conditions in which the distances from target, shot placement and angle of entry, were not standardized (Knott et al. 2009).

We recognize that hunters cannot control these variables while in the field pursuing game. This experimental design allowed us to better manage variability and relative comparison in fragmentation caused by factors other than the type of ammunition or firearm used. We also acknowledge that there is a wide variety of bullet types and many factors involved in how a chosen bullet would fragment, as well as factors that determine the deposition of fragments within a shot animal. However, our findings illustrate how far the metallic fragments can travel away from the wound channel resulting in significant deposition in the abdominal viscera primarily that is typically left in the field when the carcass is dressed. We suggest that hunters will inadvertently leave a substantial amount of lead for scavengers to consume when leaving the offal piles of the harvested animals in the field.

Management implicatons

Secondary lead poisoning in wildlife,

particularly avian species, occurs after scavengers ingest spent lead that is contained within either unretrieved game or viscera from game shot with lead-based projectiles (Fisher et al. 2006, Hunt et al. 2006, Cruz-Martinez et al. 2012). Lead-free bullets represent an alternative for hunting because the wounding potential is comparable to that of lead-based bullets tested in real hunting scenarios (Trinogga et al. 2013) and on terminal ballistic studies using ballistic soap (Gremse et al. 2014). Wherever lead-based bullets are used for hunting, there is the potential that lead will be made available to scavenger species (Hunt et al. 2006, Knott et al. 2009). We encourage hunters and wildlife managers to use lead-free bullet, particularly when dispatching animals whose remains might be left available for scavenging. We also encourage ammunition manufacturers to expand the availability of lead-free bullets.

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