EXAMINING VARIABILITY ASSOCIATED WITH BULLET FRAGMENTATION AND DEPOSITION IN WHITE-TAILED DEER AND DOMESTIC SHEEP: PRELIMINARY RESULTS

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The document is a preliminary assessment of results will be subjected to additional analysis. Results may be published in a peer-reviewed journal; hence, our findings may change as result of further analysis.

SUMMARY OF FINDINGS

Lead (Pb) is a toxic metal and is a primary material in most bullets used to hunt white-tailed deer. We conducted a study to examine bullet fragmentation patterns and to assess lead levels in deer and domestic sheep using different types of bullets and firearms. The firearms we tested included a centerfire rifle, a shotgun, and an inline muzzleloader. For the centerfire rifle, we used lead bullets that were designed to expand rapidly upon impact and were frequently described by manufacturers for hunting mid-sized game such as deer. We also tested lead bullets that were designed to retain a high percentage of their bullet weight, and non-lead (Copper [Cu]) bullets. For the muzzleloader, we chose two bullets that represented common types used during Minnesota's hunting seasons. For the shotgun, we chose the 1-ounce Foster slug, which is commonly used throughout the shotgun-only zone.

INTRODUCTION

This issue of lead in venison surfaced in late winter 2008 when several samples of ground venison from North Dakota's venison donation program tested positive for the presence of lead. Since Minnesota had a similar donation program, we also tested a sample of both ground and whole muscle cuts. Ultimately, 27% of the ground venison and 2% of the whole muscle cuts had detectable metal fragments. Laboratory testing of a sub-sample of product determined the metal fragments were lead. The Minnesota Department of Natural Resources (DNR) initiated this study to improve our understanding of bullet fragmentation patterns in carcasses.

Rifle ammunition varies tremendously in both caliber and bullet design. Although there are numerous types of specific bullets available to hunters, all bullets generally fit into one of two categories. One type of bullet is a "rapid expansion" bullet that is designed to mushroom (expand) quickly upon impact. The other type of bullet is a "controlled expansion" bullet that is designed to mushroom slowly and penetrate through bones and thick muscle tissue. Typically, inexpensive bullets designed for hunting deer have soft points and expand rapidly. In contrast, controlled expansion bullets are generally designed for hunting large mammals such as elk. Some manufacturers also offer bullets that are made entirely from copper or a copper-based alloy. These bullets are often described as: 1) "lead-free" to comply with non-toxic state regulations (e.g., California) and, 2) able to retain >95% of its weight after striking the animal, which implies that the bullet is not designed to fragment inside the animal.

In southern Minnesota, the only legal ammunition for deer hunting during the regular firearms season is a shotgun slug (muzzleloaders are also legal). The traditional slug is often referred to as a "Foster-style Slug". The Foster Slug is lead-based and is the most common type of shotgun cartridge purchased for deer hunting.

The number of deer harvested in Minnesota during the muzzleloader season has substantially increased over the past decade, particularly over the past 5 years. For this study, we chose two bullet types: 1) lead-core bullet designed specifically for muzzleloaders and 2) jacketed pistol bullet that fits into a plastic jacket.

Our intent was to conduct an experiment that would control for the caliber and focus on examining the variability of lead fragmentation and deposition associated with different categories of bullets and firearms used to harvest deer in Minnesota. Although the amount of lead deposited in animal carcasses will likely vary based on caliber due to different bullet weights associated with different calibers, we believed measuring specific types of bullets (Rapid Expansion, Controlled Expansion, and Copper) would provide meaningful results that may be generalized among various rifle calibers. We selected bullets based on descriptions of their performance and consumer availability. After examining descriptions associated with different types of bullets, we assumed that bullets designed to rapidly expand should be similar among manufacturers. For example, manufactures similarly described the performance of their soft point bullets; therefore we had no reason to believe there would be differences in performance between manufacturers. Similarly, we selected the controlled-expansion bullet based on the manufacturers description of bullet performance (retaining at least 90% of the bullet weight).

Finally, the primary objective of this study was to examine lead fragmentation patterns and to assess lead deposition in carcasses shot with different types of bullets and firearms. Our goal was to provide guidance for those individuals who are concerned about lead exposure by providing information about options that an individual may control to reduce the risk of lead exposure. We did not test the impact distance or angle an animal was standing relative to the hunter as those variables are difficult to control. In contrast, hunters can easily determine the type of bullet they intend to use before entering the deer stand. Thus, examining bullet fragmentation patterns associated with distinctly different types of bullets seemed to be the most reasonable approach because hunters can apply those results immediately, prior to the hunting season.

METHODS

This study began in the spring of 2008 and the goal was to have results available by late summer 2008. It was logistically impossible to obtain an adequate sample size of deer in late spring/early summer 2008. Thus, we used domestic sheep as a surrogate to white-tailed deer. Domestic sheep are ruminants, are anatomically similar to deer, and were available for this study. Further, domestic sheep have comparable weights and thoracic dimensions to white-tailed deer.

Eight deer were killed on 23 April 2008 using a .308 Winchester with 150 grain Nosler Ballistic Tip bullets. The deer were killed in Permit Area 101 as part of a bovine tuberculosis (TB) deer population reduction effort and were transported to the Farmland Wildlife Research Group to be stored in a walk-in freezer. The sharpshooter estimated that deer were shot <100 meters from where the sharpshooter was standing. These deer were not eviscerated until the animals arrived at the necropsy laboratory in July.

We also used 72 euthanized, domestic sheep for this study. We obtained euthanized sheep, marked the coat with a bulls-eye using non-lead spray paint and then marked the carcass for identification purposes. Each sheep was propped up in a broadside position then shot in the thoracic cavity at 50 meters (about 54 yards). A chronograph was used to record velocity, and bullets were recovered using a box filled with sand that was placed immediately behind the carcass. We recognized that sand is not the ideal material for recovering bullets and the sand may cause further disruption of the bullet. However, a more complicated water system or use of ballistic gelatin would have been cost-prohibitive and/or delayed implementation of the project. Since each bullet was recovered in the same manner, we assumed the results were comparable among bullet designs.

The treatments for this study included centerfire rifle, muzzleloader, and shotgun. For the centerfire rifle, we tested three different types of bullets while using a .308 Winchester and 150 grain bullets:

1. Rapid Expansion Bullets – Nosler Ballistic Tip and Remington Core-Lokt (soft point design)
2. Controlled Expansion Bullets – Hornady InterBond and Winchester XP^3
3. Copper Bullets – Barnes TSX

For the muzzleloader, we used a .50 caliber, 100 grains of powder (2, 50 grain Hodgdon 777 pellets), and two different bullet designs:

1. 245 grain Powerbelt Aero-Tip
2. 300 grain Hornady XTP

For the shotgun, we used a 12 gauge and a 1-ounce Foster slug (Remington). Additionally, we shot three sheep in the pelvic region using a Ballistic Tip Bullet, Remington Core-Lokt Bullet, and Remington Foster Slug to describe the dispersion of lead in animals shot in a poor location. While these data were not used in the final data analysis, we believed the associated radiographs from these sheep contributed to our understanding of overall bullet fragmentation. No statistical analyses of lead levels or fragmentation counts were conducted with these radiographs. We intended to simply describe our general observations from the radiographs and include these radiographs in the Appendix.

Bullet fragments were analyzed using radiography (X-ray) at the University of Minnesota. We skinned and gutted each carcass, inserted a carbon fiber tube through the wound channel then took a radiograph on the exit wound side. To test the effects rinsing had on bullet fragment numbers, we thoroughly rinsed the carcasses that were shot with rapid expanding bullets with water, inserted a carbon fiber tube through the wound channel, and then took a second radiograph. Due to logistical constraints, we did not take a second radiograph of sheep shot with non-rapid expansion bullets. A veterinarian measured the maximum distance of fragments in relation to the carbon fiber tube, counted the number of fragments that were observable on radiographs taken using a ventral-dorsal (animal on its back) view of the sheep, and counted the number of fragments within two inches of the exit hole on radiographs taken using a lateral (animal on its side) view of the animal. Radiographs were coded so that the veterinarian did not know the type of bullet used on individual radiographs taken on each sheep.

The extent of lead contamination in muscle tissue was determined by using techniques similar to other published studies. We collected a muscle tissue sample from 2, 10, and 18 inches from the exit wounds (Fig. 1). To assess the effects rinsing has on lead contamination, we rinsed carcasses shot by all bullet types and collected another three muscle tissue samples at the same distances.

We also measured the diameter of the entry/exit holes on each carcass. These measurements were used as a "killing power" index to illustrate the potential effectiveness of each bullet type for killing deer. Finally, we measured the wound channel lengths (linear distance between the entry and exit wound) so that anatomical comparisons could be made between deer and sheep..

RESULTS AND DISCUSSION

General Performance

We observed little variability in bullet velocity among centerfire rifle bullets; however, there were noticeable differences in velocity among firearms. (Table 1). Weight retention of bullets after being recovered in the sand was variable (Table 1). Both rapid expansion bullets (Nosler Ballistic Tip, Remington Core-Lokt) retained about 48% of their weights. We noticed that Nosler Ballistic Tips had almost no variability in bullet weights after being collected in the sand. We believe this was due to the fact that, in all cases, the lead completely separated and all that was left was the copper jacket (Figure 1). In comparison, the Remington Core-Lokt bullets retained about 48% of their weight but there was more variation in recovered bullet weights because in some cases, lead remained adhered to the jacket. There was a substantial difference in bullet weight retention between the controlled expansion bullets. The Hornady InterBond bullet retained about 76% of its weight while the Winchester XP^3 retained about 91% of its weight. For rifle bullets, the Barnes TSX retained most of its bullet weight (96%). Both muzzleloader bullets and the shotgun slug also retained >90% of their original weight (Table 1).

Bullet Fragmentation

There were marked differences in the total number of bullet fragments counted on radiographs among different bullet types (Table 2). Clearly, the Winchester XP^3, Barnes TSX, and the Powerbelt resisted fragmentation whereas the other bullets fragmented. Variability associated with fragment patterns was noteworthy, particularly for the Nosler Ballistic Tip and Hornady InterBond bullets. The number of fragments counted on radiographs of sheep shot with shotgun slugs and muzzleloaders were noticeably lower than the number of fragments counted on radiographs of sheep shot with rapid expanding bullets. Similarly, there were differences in the number of fragments counted within 2 inches around the exit hole among bullet types (Table 3).

The average estimated maximum distance a fragment was observed relative to the exit hole was >5 inches for all bullet types except the Barnes TSX and the Powerbelt (Table 4).

Lead Levels in Muscle Tissue Samples

The level of lead (ppm) in tissue samples varied both across bullet types and at different distances from the exit hole. With the exception of the Winchester XP^3 and Barnes TSX, centerfire rifle bullets had markedly higher levels of lead in tissue samples than bullets shot with other firearms (Table 5). Lead levels were much higher in tissue samples collected 2 inches from the exit hole as opposed to 10 or 18 inches away.

Effects of Rinsing on Fragments and Lead Levels

Rinsing reduced the level of lead in tissue samples; particularly samples collected 2 inches from the exit hole (Tables 5 and 6). However, our data might indicate that rinsing the carcass only spread the lead contamination from highly concentrated levels near the exit hole to other areas of the carcass. Prior to being rinsed (Table 5), only 2 tissue samples from different bullet types tested positive for a low level of lead 18 inches away from the exit hole. In contrast, 5 tissues samples from different bullet types tested positive for lead after the carcass was rinsed (Table 6). Overall, lead levels from sheep shot using non-centerfire firearms, the Winchester XP^3, and Barnes TSX bullets had lower pre-rinse lead levels than Nosler Ballistic Tips, Remington Core-Lokts, and Hornady InterBonds did after the carcass was rinsed (Tables 5 and 6).

Rinsing also tended to slightly reduce the number of fragments counted on radiographs (Table 7). In general, the numbers of fragments observed after the rinse was 5 to 20% lower than the number of fragments counted prior to the rinse. The effect rinsing had on the maximum distance a fragment was observed from the exit hole was negligible.

Killing Power Indices

Carcass weights were higher for deer than for sheep, but wound channel lengths were comparable between species (Table 8). Entry holes were smaller for the controlled expanding centerfire rifle bullets (Hornady InterBond and Winchester XP^3) and highest for the Hornady XTP (muzzleloader bullet). Excluding the Powerbelt (muzzleloader bullet), average exit hole diameters had little variation among bullet types ranging from 1.7 - 2.0 inches on sheep.

Pelvic Region

We observed high levels of fragmentation with both the Nosler Ballistic Tip and Remington Core-Lokt bullets. In fact, the X-rays of both bullets looked similar even though only the Nosler Ballistic Tip hit bone. In other words, the Remington Core-Lokt bullet hit only muscle, yet the fragmentation pattern between both centerfire bullets looked similar. For the Remington slug, both femurs were broken but the degree of fragmentation was low, which further suggests that lower fragmentation levels are associated with bullets that have more mass and are shot at lower velocities.

DISCUSSION

The results from our study suggest that bullet fragmentation patterns are dependent on the type of bullet. We observed few fragments on radiographs of carcasses shot using Winchester XP^3 and Barnes TSX bullets. Both of these bullets were described by manufacturers as retaining >95% of their weight, so these results were expected based on that marketing information. However, the Hornady InterBond bullet was described as retaining >90% of its weight, but in this study, it performed similarly to the bullets that were marketed as those designed to expand rapidly (Nosler Ballistic Tip and Remington Core-Lokt bullets).

Bullet fragmentation patterns were highly variable within and among bullet types. Both rapid expanding bullets (Nosler Ballistic Tip and Remington Core Lokt) and the Hornady InterBond had high fragment counts and the fragments were distributed 5 - 14 inches away from the exit hole. In contrast, the Barnes TSX bullet had low fragment counts and the average maximum distance the maximum was in relation to the exit hole was 4 inches. We also found that the Winchester XP^3 had low fragment counts, but we did observe a metal fragment about 11 inches away from the exit hole. These fragments were likely copper because, 1) recovered bullets did not reveal any exposed lead, and 2) there was no detectable lead in the muscle samples. An important constraint of this portion of the study was that we did not take X-Rays of the entire carcass; therefore, the possibility exists that fragments may have travelled further than we described.

The lead level in the tissue sample data further demonstrates the pattern of lead associated with the wound channel. Bullet fragments were concentrated closer to the exit hole and became less concentrated as the distance away from the exit increased. The probability of having a tissue sample test positive for lead at 10 inches away from the bullet hole was quite low (~7%), but we still detected lead in tissue samples obtained from sheep shot using the Nosler Ballistic Tips and Hornady InterBonds as far as 18 inches away from the exit holes.

We predicted that animals shot with shotgun slugs and muzzleloader bullets would contain less lead as compared to those shot with centerfire rifles due to the greater mass of the bullet and lower velocities associated with the bullets shot from these firearms. Our data confirmed that the number of fragments and lead levels in tissue samples should be lower in deer shot with shotgun slugs or muzzleloaders compared to those shot using rapid expanding centerfire rifle bullets. However, risk of exposure to lead was not eliminated. Fragments were readily apparent in carcasses shot using both shotgun slugs and muzzleloader bullets. We speculate that the biggest difference between these firearms and centerfire rifles is the “lead dust”, or extremely small bullet fragments, created by high velocity centerfire rifle bullets. Although shotgun slugs and muzzleloader bullets will both fragment, small lead dust particles may not be created from the bullets due to the lower bullet velocity. However, this study was not designed to address microscopic fragmentation.

The effects rinsing had on managing risk of lead exposure to humans consuming venison was mixed. This study suggests that rinsing the carcass reduced the level of lead in tissue samples close to the exit hole. However, it appears to have increased the level of contamination in other areas of the carcass. If the muscle tissue immediately surrounding the exit hole is not used for human consumption, it is likely a better option to not rinse the carcass so that the lead is not spread to other areas of the carcass where the muscle tissue will be consumed. Based on our results, rinsing the carcass is a less effective option than simply choosing a bullet that is designed to resist fragmentation.

With respect to the numbers of fragments and lead levels, there were noticeable differences between deer and sheep carcasses shot with Nosler Ballistic Tip bullets. We believe the variability in distances and angles deer were shot from the sharpshooter explain these differences. Wound channel lengths were comparable between deer and sheep; therefore, we expected bullet fragmentation patterns to be nearly equivalent because the amount of tissue bullets traveled through the cavity of animals would be similar as well. The primary difference between these groups of animals was that all sheep were shot in a broadside position at 50 m from the shooter but all deer were shot at different angles and distances by the sharpshooter. We considered testing the effects different distances had on fragmentation patterns when we initiated the study. However, we could not justify increasing our sample size of sheep to test for the effect distance had on fragmentation patterns because hunters are generally unable to manage the distance an animal is relative to their deer stand. We believed it was more logical to test different types of bullets because individuals can clearly determine which type of bullet they intend use while hunting. The deer used in our sample were frozen for about three months prior to being analyzed and we cannot be certain that freezing did not impact our results. Perhaps more lead was removed from the cavities of deer while the previously frozen organs were removed during the evisceration process. Regardless, we believe that the results of our study would not have been different had we used 72 deer rather than 72 sheep. We are confident that fragmentation patterns and lead level data will be lower in any animals shot by Winchester XP^3 and Barnes TSX bullets compared to bullets that are designed to expand rapidly in any future studies. We believe the results from this study can be used for hunters who intend to hunt other mid-sized game mammals, such as pronghorn antelope or mule deer.

In conclusion, this study suggests that an individual can manage their risk of exposure to lead by selecting an appropriate bullet design. Individuals who wish to reduce their risk of exposure to lead should use a non-lead bullet or a lead-based bullet where the lead is not exposed to the animal (e.g., Winchester XP^3). Several caveats need to be included with our conclusions. First, previous studies have demonstrated that deer can recover after being shot by a hunter. Thus, hunters who use non-lead bullets still need to recognize that there is some risk of lead exposure because the deer they harvested may have been shot during a previous hunting season. In addition, having venison processed at a meat processor will likely result in an increased risk of lead exposure because venison from different hunters is typically mixed during the grinding process and the vast majority of hunting bullets are made from lead. Our study was not designed to address either of these issues, but concerned hunters should recognize that some level of risk of lead exposure exists even though they chose to purchase a non-lead bullet. The results from this study can be used as a framework to manage risk of exposure, but there are additional risks of exposure to consider.

Implications for hunters

- Hunters can manage their risk of lead exposure by selecting an appropriate bullet design. However, bullets described as high weight retention bullets may still fragment and contaminate carcasses with lead.
- We detected lead in tissue samples that were 18 inches from the exit hole (the maximum we could measure on X-Ray). Therefore, we were not able to conclude that there was a distance from the exit hole where lead would not be detected.
- Levels of lead (ppm) varied among bullet types with lowest lead levels (0) associated with the Winchester XP^3 and Barnes TSX (non-lead bullet).
- Slugs and muzzleloader bullets fragmented less than rifle bullets; however, lead was detected in tissue samples of carcasses shot with these firearms. Our data confirm that the mass of these bullet weights and the lower velocities associated with these projectiles affect bullet fragmentation patterns.
- Rinsing the carcass did not eliminate lead from carcasses. Our data suggest rinsing the carcass may have spread the contamination to other areas of the carcass. Selecting a proper bullet design is more important than a hunter's decision to rinse the carcass to reduce lead contamination. Hunters who normally rinse their carcasses should also be aware that rinsing will likely spread lead to other areas of the carcass.
- Controlled expansion and copper bullets created exit holes that were comparable in size to rapid expansion bullets.

Table 1. Bullet speed (feet per second) and recovered bullet weights.

	Rifle					Muzzleloader		Shotgun
	Nosler Ballistic Tip	Remington Core-Lokt	Hornady Inter-Bond	Winchester XP^3	Barnes TSX	Hornady XTP	Powerbelt Aero-Tip	Rifled Slug
Mean (fps)	2,875	2,902	2,806	2,932	2,856	1,590	1,558	1,483
Std. Dev.	32.7	55.3	38.0	63.8	99.4	11.0	53.0	126.3
Min	2,825	2,834	2,717	2,875	2,781	1,576	1,489	1,219
Max	2,938	3,014	2,838	3,078	3,111	1,601	1,616	1,714

Recovered Bullet (Weights in grains)								
Original Weight	150	150	150	150	150	300	245	440
Recovered Weight	72.4	72.6	114.6	136.7	144.7	272.5	235.4	423.7
Std. Dev.	3.1	25.8	23.5	11.2	5.9	9.1	18.8	14.7
% Retained	48%	48%	76%	91%	96%	91%	96%	96%

Table 2. Total number of bullet fragments counted on lateral radiographs.

Species	Bullet Type	Sample Size	Average	Standard Error	Minimum	Maximum
Deer	Nosler Ballistic Tip	8	60	30	7	261
Sheep	Nosler Ballistic Tip	9	141	45	74	498
Sheep	Remington Core-Lokt	10	86	11	28	138
Sheep	Hornady Interbond	10	82	20	21	218
Sheep	Winchester XP^3	10	9	2	2	28
Sheep	Barnes TSX	10	2	<1	1	4
Sheep	Foster Slug	8	28	15	3	127
Sheep	Powerbelt Aero-Tip	6	3	1	1	9
Sheep	Hornady XTP	6	34	15	6	105

Table 3. Total number of bullet fragments counted within 2 inches of the exit hole on lateral radiographs.

Species	Bullet Type	Sample Size	Average	Min.	Max.	Percent 2” around exit hole
Deer	Nosler Ballistic Tip	7	18	2	43	30%
Sheep	Nosler Ballistic Tip	9	41	13	86	29%
Sheep	Remington Core-Lokt	10	43	15	92	50%
Sheep	Hornady Interbond	10	36	11	83	44%
Sheep	Winchester XP^3	10	<1	0	3	11%
Sheep	Barnes TSX	10	<1	0	2	50%
Sheep	Foster Slug	9	12	1	31	43%
Sheep	Powerbelt Aero-Tip	6	2	0	10	67%
Sheep	Hornady XTP	6	21	3	62	62%

Table 4. Maximum distance (inches) a bullet fragment was observed from the exit hole.

Species	Bullet Type	Sample Size	Average Maximum	Standard Error	Minimum	Maximum
Deer	Nosler Ballistic Tip	7	8	1	6	10
Sheep	Nosler Ballistic Tip	9	11	1	7	14
Sheep	Remington Core-Lokt	10	11	1	9	13
Sheep	Hornady Interbond	10	9	1	5	11
Sheep	Winchester XP^3	10	7	1	4	11
Sheep	Barnes TSX	10	<1	1	0	3
Sheep	Foster Slug	9	5	1	0	11
Sheep	Powerbelt Aero-Tip	6	1	1	0	5
Sheep	Hornady XTP	6	6	1	0	12

Table 5. Average parts per million of lead in tissue samples collected at different distances away from the exit hole of animals shot using different types of bullets.

		Distance from exit hole (inches)		
Species	Bullet Type	2	10	18
Deer	Nosler Ballistic Tip	1	0	0
Sheep	Nosler Ballistic Tip	67	18	1
Sheep	Remington Core-Lokt	157	2	0
Sheep	Hornady Interbond	95	1	1
Sheep	Winchester XP^3	0	0	0
Sheep	Barnes TSX	0	0	0
Sheep	Foster Slug	1	0	0
Sheep	Powerbelt Aero-Tip	0	0	0
Sheep	Hornady XTP	0	2	0

Table 6. Level of lead (ppm) in tissue samples collected after carcasses were rinsed at different distances away from the exit hole of animals shot using different types of bullets.

		Distance from exit hole (inches)		
Species	Bullet Type	2	10	18
Deer	Nosler Ballistic Tip	7	1	0
Sheep	Nosler Ballistic Tip	14	5	83
Sheep	Remington Core-Lokt	5	23	1
Sheep	Hornady Interbond	11	3	1
Sheep	Winchester XP^3	0	0	0
Sheep	Barnes TSX	0	0	0
Sheep	Foster Slug	2	1	3
Sheep	Powerbelt Aero-Tip	0	0	0
Sheep	Hornady XTP	0	1	1

Table 7. The average number of fragments counted, and the average estimated maximum distance (inches) a fragment was from the exit hole before and after rinsing the carcass, using different bullet types on white-tailed deer and domestic sheep.

		Fragments within 2 inches of the exit hole		Total fragments counted		Maximum distance from exit hole	
Species	Bullet Type	Pre-rinse	Post-rinse	Pre-rinse	Post-rinse	Pre-rinse	Post-rinse
Deer	Nosler Ballistic Tip	18	19	60	57	8	10
Sheep	Nosler Ballistic Tip	41	39	141	120	11	10
Sheep	Remington Core-Lokt	45	39	86	70	11	10
Total		36	33	97	83	10	10

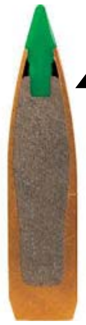
Table 8. Average entry and exit hole diameters (in inches), wound channel lengths (distance between entry and exit holes in inches), and weights (in pounds) of white-tailed deer and domestic sheep shot with different bullet types and weapons, Minnesota, 2008.

Weapon	Bullet Type	Species	N	Carcass Weight	Entry Hole	Exit Hole	Wound Channel
Rifle	Nosler Ballistic Tip	Deer	8	68	1.0	2.7	8.6
	Nosler Ballistic Tip	Sheep	10	43	1.0	2.0	8.9
	Remington Core-Lokt	Sheep	10	34	1.1	1.9	7.2
	Hornady Interbond	Sheep	10	29	0.6	1.8	7.8
	Winchester XP^3	Sheep	10	45	0.7	1.7	9.3
	Barnes TSX	Sheep	10	38	0.8	2.0	7.7
Shotgun	Foster Slug	Sheep	10	48	1.3	1.7	7.8
Muzzleloader	Powerbelt Aero-Tip	Sheep	6	37	0.9	1.2	6.0
	Hornady XTP	Sheep	6	46	1.3	1.7	7.4

Figure 1. Anatomy of centerfire rifle bullets used in this study.

Rapid Expansion

Nosler Ballistic Tip



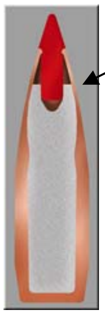
Poly-carbonate tip, thin copper jacket that tapers toward the base. Lead core.

Remington Core-Lokt

Thin copper jacket, lead core that is ‘locked’ by the jacket to increase expansion.

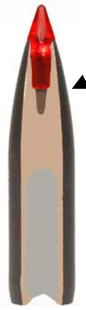
Controlled Expansion

Hornady InterBond



Poly-carbonate tip, thick copper jacket with a ring to increase expansion. Lead core is bonded to the jacket so it does not separate.

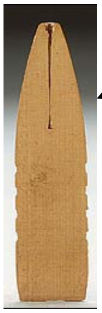
Winchester XP^3



Poly-carbonate tip, copper jacket is bonded to lead core. Design is such that the copper completely surrounds the lead core.

Copper

Barnes TSX



All-copper design. Upon impact, the bullet expands into four petals that are designed to not separate.