Lead concentrations in white-tailed deer tissue due to retained bullets

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Abstract: Mobilization of lead from retained bullets may lead to elevated lead levels in game tissue with consequences for consumers. We investigated lead mobilization in 2 white-tailed deer *(Odocoileus virginianus)* carrying retained lead ammunition from previous gunshot wounds. Lead concentrations in muscle tissue of deer with retained lead bullets were in the same range as control deer. In contrast, 1 deer had higher bone lead levels than controls, suggesting mobilization occurred. Our results suggest that lead mobilization to meat from retained lead bullets does not appear to pose a consumption risk for those consuming meat that is physically distant from lead particles embedded within the carcass.

Key words: ammunition, bullet fragmentation, hunting, lead exposure, lead mobilization, *Odocoileus virginianus*, retained bullets, white-tailed deer

Previous research on risks posed by lead ammunition in wildlife has primarily focused on ingestion by carcass scavengers (e.g., Hunt et al. 2006, Sieg et al. 2009, Bedrosian et al. 2012, Legagneux et al. 2014), consumption of lead ammunition particles in game meat by humans (e.g., Iqbal et al. 2009, Morales et al. 2011, Fachehoun et al. 2015, Buenz et al. 2016), and bullet fragmentation (e.g., Grund et al. 2010, Cruz-Martinez et al. 2015). These studies focused on immediate impacts of bullets and bullet fragments, but game animals may recover from bullet wounds and retain lead ammunition within their bodies. Hence, retained bullets in game may pose health hazards if lead is mobilized to commonly consumed areas of the body.

Implanting lead bullets in rats (*Rattus norvegicus domesticus*) resulted in lead mobilization to critical organs, although blood lead levels sometimes remained unchanged (Celbis et al. 2011). Similarly, lead from retained ammunition can increase blood lead concentrations in humans (McQuirter et al. 2001, McQuirter et al. 2003, de Araújo et al. 2015). Length of time that bullets are carried impacts lead concentration, as blood lead levels in humans increase with time following gunshot (McQuirter et. al 2003). Although little is known about the impact of retained lead ammunition on game meat, retained lead projectiles may cause elevated hepatic lead levels in wildlife (LaDouceur et al. 2015). Bullet fragmentation also impacts lead concentration. Bullet fragmentation increases surface area of lead in contact with animal tissues, which may increase absorption. Bullets used to harvest game can deposit lead fragments over large portions of carcasses (Grund et al. 2010, Cruz-Martinez et al. 2015), and blood lead levels in humans increase with the number of retained fragments from gunshot injury (McQuirter et al. 2003).

Little is known about the impact of retained lead-based bullets from previous gunshot wounds on lead concentrations in game animals. We investigated the impact of retained bullets on lead concentration in muscle and bone tissue of wild white-tailed deer (*Odocoileus virginianus*; deer). Given the potential for lead to mobilize within an animal, we expected that retained bullets might impact lead concentrations beyond the area containing the bullet or bullet fragments.

Study area

The deer used in this study were harvested on a 400-ha privately owned property in Litchfield County, Connecticut, USA (41° 47′ N and 73° 16′ W). The climate of the area is characterized

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as temperate with mild winters and warm summers; average annual precipitation is 122 cm, and average annual temperature is 7.8°C (National Oceanic and Atmospheric Administration 2018). The property is primarily mature forest and is managed for timber production; the dominant habitat type is temperate deciduous seasonal forest. The vegetation of the study area is dominated by chestnut oak (*Quercus montana*) in the rocky uplands with an understory of mountain laurel (*Kalmia latifolia*). Red maple (*Acer rubrum*) is dominant in moist lowlands with an understory of spicebush (*Lindera benzoin*).

Methods

We compared 2 free-ranging deer carrying a retained bullet to 4 control deer (C1–C4) that had no signs of previous lead exposure. Of the 2 deer with previous lead exposure, 1 deer carried a highly fragmented rifle bullet (R1) and the other an intact air rifle pellet (R2). All 6 deer were healthy with no noticeable signs of disease or injury. The gunshot wounds in both focal deer were completely healed and likely occurred several months, if not years, previous. The deer studied were harvested by a licensed hunter during seasons regulated by the Connecticut Department of Energy and Environmental Protection from 2009 to 2011 and were not killed for the purpose of obtaining tissue samples. All material used in the study was collected in the course of normal butchering for personal consumption by the hunter. Harvest method varied among individual deer (archery gear: deer C1 and C2; copper rifle bullet: R1 and R2; copper muzzleloader bullet: C3; copper jacketed lead shotgun slug: C4); however, none were harvested using high-velocity lead-based rifle bullets. Because high-velocity lead-based ammunition was not used for harvest, it is unlikely that errant lead particles contaminated any of the samples.

Muscle samples were taken from the hindquarter, as this was distantly removed from the location of gunshot injury and represents a commonly consumed meat source. Bone samples were taken from the area of the skull between the antlers. Bone samples were air-dried and ground through 20 mesh in a Wiley Mini-Mill. Samples were taken from the muscle tissue of all 6 deer and bone tissue of 5 of the 6 deer. Lead content was analyzed using inductively coupled plasma mass spectrometry (ICP-MS) on an Agilent 7500cx ICP-MScx by Analytical Sciences Laboratory, University of Idaho (Moscow, Idaho, USA). Bone samples were analyzed and reported on a dry weight basis and muscle tissue samples by wet weight.

A subsample (approximately 25 g) of lead-containing muscle tissue was collected from the region with visible particles from the deer with the highly fragmented bullet. This sample was not intended to be a representative sample of lead content; rather, it was collected to preserve tissue with the largest lead particles. The tissue was digested in 2-molar sulfuric acid to dissolve tissue but not lead. This was done to separate and weigh the quantity of lead in the subsample and enabled visualization of fragmentation for the deer carrying the highly fragmented rifle bullet. The lead air rifle pellet was similarly removed from the carcass, retained, and weighed.

Results

The deer that carried the highly fragmented rifle bullet was previously struck just behind the scapula and above the vertebral column. The wound was completely healed at the time of harvest. The portion of the bullet that was retained was unclear. All particles found were visibly identified as lead with no evidence of a copper bullet jacket. Lead particles were concentrated in a 10-cm portion of the Longissimus dorsi and the connective tissue of the adjacent spinous processes. This tissue contained many hundreds of particles too small to feel, and portions were stained dark metallic silver. We isolated nearly 300 particles following digestion; most were minute, but there were also a few larger fragments (Figure 1). The subsample contained 0.48 g (7.4 grains) of lead, which represented <25% of the overall lead in the deer given the extent of the particles visibly observed but not collected.

The deer with the retained air rifle pellet showed no external signs of wounding from the retained bullet. The bullet was located in the muscle tissue of the forearm and was not in contact with bone. There was no discoloration or staining of the tissues surrounding the bullet. The air rifle pellet was fully intact (Figure 1) and weighed 0.49 g (7.5 grains).

Figure 1. Lead bullets recovered from white-tailed deer (*Odocoileus virginianus*) from Litchfield County, Connecticut, USA, 2009–2011. An intact air rifle pellet (left), and a subset of the particles of a highly fragmented rifle bullet (right) are shown. Horizontal bar at lower right represents 1 cm.

Lead concentration in the muscle tissue of the deer with previous lead exposure was 0.009 μg/g for the deer with the highly fragmented rifle bullet and 0.007 μg/g for the deer with the intact air rifle pellet. Muscle tissue lead concentration of control deer averaged 0.015 μg/g, which was similar to the 2 focal deer with retained bullets (muscle tissue lead of control deer: 0.008 μg/g [C1], 0.009 μg/g [C2], 0.019 μg/g [C3], 0.025 μg/g [C4]). Lead concentration in bone tissue was 171.00 μg/g for the deer with the intact air rifle pellet, which was the highest bone lead level of all deer tested. However, the deer that retained fragments from a rifle bullet had a bone lead concentration of 50.80 μg/g, which was comparable to the control deer that averaged 35.0 μg/g (bone tissue lead of control deer: 67.54 μg/g [C1], 7.27 μg/g [C2], 30.16 μg/g [C3]).

Discussion

Direct consumption of lead bullets in carcasses is linked to scavenger exposure to lead (Hunt et al. 2006). Scavenging birds acquire lead from hunter-shot deer (Cruz-Martinez et al. 2012), which increases blood lead content (Legagneux et al. 2014) and distribution of lead throughout the organism (Behmke et al. 2017). Similarly, when fed meat containing lead ammunition, domestic pigs (*Sus scrofa*) show increased blood-lead concentrations (Hunt et al. 2009), and dogs (*Canis lupus familiaris*) show risk of lead intoxication (Hogasen et al. 2016). Although direct consumption of lead may be a significant problem for wildlife populations, the risks to humans who eat game meat containing lead particles are poorly understood. There is evidence that consumption of wild game (Iqbal et al. 2009) or game harvested with lead ammunition (Buenz and Parry 2018) causes elevated blood lead levels in humans, but the impact of retained lead-based ammunition remains unknown.

We found that the deer carrying an intact air rifle pellet did appear to mobilize some lead, evidenced by nearly 5 times higher lead levels in bone tissue than the other deer. Although the conclusions of our natural experiment were constrained by small sample size and lack of replication, some mobilization to bone tissue is not surprising given that lead from retained bullets can mobilize to critical organs in rats (Celbis et al. 2011) and to the bloodstream in humans (McQuirter et al. 2001, McQuirter et al. 2003, de Araújo et al. 2015). Bone serves as

a reservoir for lead accumulation, and bone lead levels are considered the best indicator for evaluating long-term lead exposure (Franson and Pain 2011). Since time from initial wounding was unknown, it is possible that the high bone lead concentration in the deer with the air rifle pellet was due to carrying the lead for a longer period of time.

We did not find evidence of lead mobilization to muscle tissue in either of the deer with retained lead-based ammunition. These findings are important because deer meat is more commonly consumed than bone tissue. We expected the deer carrying the highly fragmented bullet to have higher lead concentrations because bullet fragmentation increases the surface area of lead in contact with tissues and because retained bullet fragmentation increases blood lead levels in humans (McQuirter et al. 2003). However, muscle tissue lead concentration of the deer with fragmented and non-fragmented lead bullets were in the same range as the controls. This is consistent with knowledge of avian species, in which lead that is embedded does not result in lead poisoning due to inadequate pH for lead dissolution (De Francisco et al. 2003).

Our findings do not provide evidence that lead mobilization from retained bullets causes elevated lead levels in muscle, suggesting that meat distantly removed from the bullet does not pose a health concern. However, consumption of muscle tissue containing fragmented lead particles from a retained bullet, which may not be noticed during butchering, remains a concern. Given the limitations of our natural experiment, further research on hazards of retained bullets in game is needed.

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