Science of the Total Environment 443 (2013) 226–232

Contents lists available at SciVerse ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Are lead-free hunting rifle bullets as effective at killing wildlife as conventional lead bullets? A comparison based on wound size and morphology

Anna Trinogga *, Guido Fritsch, Heribert Hofer, Oliver Krone

Leibniz Institute for Zoo and Wildlife Research, P.O. 601103, D-10252 Berlin, Germany

HIGHLIGHTS

- ► Wound diameters do not differ between lead-free and lead-based hunting rifle bullets.
- ► The size of the wound's maximum cross-sectional area does not depend on bullet material.
- ► Lead-free rifle bullets represent a suitable alternative to conventional bullets.
- ► The use of non lead bullets is appropriate to prevent lead deposit in the ecosystem.

ARTICLE INFO

Article history:
Received 3 September 2012
Received in revised form 22 October 2012
Accepted 22 October 2012
Available online 25 November 2012

Keywords:
Computed tomography
Game animals
Lead poisoning
Rifle bullets
Sustainable hunting
Wounding potential

ABSTRACT

Fragmentation of the lead core of conventional wildlife hunting rifle bullets causes contamination of the target with lead. The community of scavenger species which feed on carcasses or viscera discarded by hunters are regularly exposed to these lead fragments and may die by acute or chronic lead intoxication, as demonstrated for numerous species such as white-tailed eagles (*Haliaeetus albicilla*) where it is among the most important sources of mortality. Not only does hunting with conventional ammunition deposit lead in considerable quantities in the environment, it also significantly delays or threatens the recovery of endangered raptor populations. Although lead-free bullets might be considered a suitable alternative that addresses the source of these problems, serious reservations have been expressed as to their ability to quickly and effectively kill a hunted animal. To assess the suitability of lead-free projectiles for hunting practice, the wounding potential of conventional bullets was compared with lead-free bullets under real life hunting conditions. Wound dimensions were regarded as good markers of the projectiles' killing potential. Wound channels in 34 killed wild ungulates were evaluated using computed tomography and post-mortem macroscopical examination. Wound diameters caused by conventional bullets did not differ significantly to those created by lead-free bullets. Similarly, the size of the maximum cross-sectional area of the wound was similar for both bullet types. Injury patterns suggested that all animals died by exsanguination. This study demonstrates that lead-free bullets are equal to conventional hunting bullets in terms of killing effectiveness and thus equally meet the welfare requirements of killing wildlife as painlessly as possible. The widespread introduction and use of lead-free bullets should be encouraged as it prevents environmental contamination with a seriously toxic pollutant and contributes to the conservation of a wide variety of threatened or endangered raptors and other members of the guild of scavengers.

1. Introduction

1.1. Lead intoxications in birds of prey

The impact of lead on the ecosystem represents an important challenge in terms of nature conservation. As lead is a highly toxic heavy metal, efforts have been made for years in order to eliminate it from the environment. Nevertheless, considerable quantities of lead are deposited in the ecosystem by hunting. Conventional hunting rifle bullets contain a lead core partially enclosed by a copper or brass jacket, a type of bullet that is called semi-jacketed. These projectiles fragment on impact on a body, leaving behind a large number of small lead particles (Cornicelli and Grund, 2008; Hunt et al., 2006, 2009b). The oral uptake of such lead fragments may result in severe and often fatal lead poisoning in raptors (Fisher et al., 2006; Hunt et al., 2006; Kenntner et al., 2001; Kramer and Redig, 1997; Krone et al., 2009; Scheuhammer and Templeton, 1998). It is a common practice among hunters to eviscerate hunted wildlife in the field, leaving

* Corresponding author at: Food and Feed Control Authority of the county of Havelland (Landkreis Havelland, Amt für Landwirtschaft, Veterinär- und Lebensmittelüberwachung), Goethestr. 59/60, D-14641 Nauen, Germany. Tel.: +49 3321 4035516; fax: +49 3321 40335516.
E-mail address: anna_trinogga@gmx.de (A. Trinogga).

0048-9697/$ – see front matter
http://dx.doi.org/10.1016/j.scitotenv.2012.10.084

behind the viscera which then are available for many scavenging species. Wounded animals represent an additional source of lead for predators. Nadjafzadeh et al. (2012) showed that not only raptors are affected but also corvids and terrestrial carnivores. Lead from spent ammunition may alter the population dynamics of these species and threaten the recovery of some highly endangered raptors such as the California condor (*Gymnogyps californianus*), Steller's sea eagle (*Haliaeetus pelagicus*), bearded vulture (*Gypaetus barbatus*) and griffon vulture (*Gyps fulvus*) (Church et al., 2006; Hunt et al., 2009a; Kim et al., 1999; Mateo, 2009; Pain et al., 2009; Saito, 2000). In Germany, the white-tailed eagle (*Haliaeetus albicilla*) represents the best studied raptor species regarding the accumulation of toxic elements. Krone et al. (2003) identified lead poisoning as the primary cause of death in white-tailed eagles found dead or moribund in Germany. Sulawa et al. (2010) demonstrated that lead intoxication is responsible for a significant reduction in the growth rate of the German white-tailed eagle population.

1.2. Lead-free bullets as one solution

In this context the question arose whether there are suitable alternatives to conventional lead-based hunting rifle bullets. Lead-free bullets made of copper or copper alloys have existed since the 1990s but their use is still highly controversial in Germany (Beyer, 2005; BfR, 2012; Grieder, 2006; Klups, 2005a–g, 2006a–f; Liese, 2012). Typically, reservations are expressed about the wounding capacity of lead-free constructions; they are said to be inferior to standard lead-based ammunition. As national and European legislation (e.g., in Germany, the Tierschutzgesetz der Bundesrepublik Deutschland, 2006) and the ethical codices of hunters in many countries claim that no unnecessary pain is to be inflicted upon a hunted and shot animal, new bullets are only accepted if their wounding and killing potential at least equals those of conventional projectiles.

1.3. Comparing the wounding potential of rifle bullets

Under comparable conditions, a similar wounding potential of different bullets should be reflected by a comparable wounding pattern. Rifle shots kill by tissue destruction (Karger, 2004; Kneubuehl et al., 2008; Sellier and Kneubuehl, 2001). The size and morphology of wounds are therefore good indicators of the killing capacity of bullets. Another method to assess the adequacy of a certain bullet or bullet type for hunting purposes is the analysis of flight distances. Stokke et al. (2012) defined maximum acceptable flight distances for several species such as moose and brown bear.

We chose the evaluation of tissue damage patterns as this approach allows for the direct comparison of the wounding potential of different bullet types even if both types meet the minimum requirements. If the performance of lead-free bullets was inferior to conventional lead-core bullets this should be reflected in the dimensions of the wounds they cause. In such a case, the wound channel diameters should be smaller than those caused by conventional lead bullets. Computed tomography (CT) and necropsy are both appropriate methods to evaluate gunshot wounds (Donchin et al., 1994; Oliver et al., 1995; Thali and Dirnhofer, 2004; Thali et al., 2003; Thali et al., 2007). Wound dimensions can easily be measured using modern CT software. Conclusions as to the actual cause of death can be drawn from the organ injuries and from typical alterations such as organ anaemia in cases of exsanguination. Evaluating wound dimensions and morphology represents the basis for the assessment of a bullet's ability to quickly and effectively kill a hunted animal. The present study was therefore designed to use such measures to answer the question whether lead-free hunting rifle bullets are an adequate surrogate for the conventional but toxic lead-based bullets and whether the use of currently available lead-free bullets can be recommended.

We were particularly interested in evaluating this question under real life practical hunting conditions. In Germany, our study area, this means hunting small to medium-sized wild ungulates shot at distances of up to 150 m with bullets having an impact energy of approximately 1500 to 3500 J. It was the aim of the present study to analyse whether lead-free hunting rifle bullets are adequate for hunting which means that they have to function properly under a variety of conditions. Evaluating the bullet potential under real life conditions implies refraining from a standardised shooting situation but taking advantage of the fact that the lead-freed bullets were used by hunters trained to make their shooting decisions using lead bullets throughout their hunting career. Shots under standardised conditions were performed as another part of the project using ballistic soap as a tissue simulant. Their results are to be presented in a subsequent paper.

2. Materials and methods

2.1. Study animals

The bodies of 65 shot wild ungulates were provided by private hunters and the forest management units of the Federal Republic of Germany and the federal states of Bavaria, Brandenburg and Schleswig–Holstein. The animals were shot during stalking and drive hunts between December 2006 and January 2009. Of these, 22 were shot into abdominal viscera, seven into the head or neck, two in the lumbar spine and 34 into the thoracic cavity.

To ensure comparability, only animals with wound channels through the thoracic cavity were included in the study, resulting in a subsample of 34 carcasses — 15 wild boar (*Sus scrofa*), 13 roe deer (*Capreolus capreolus*), four chamois (*Rupicapra rupicapra*), one red deer (*Cervus elaphus*) and one fallow deer (*Cervus dama*). Each animal was placed in a cooling chamber (4 °C) immediately after the hunt and frozen at −20 °C as soon as possible.

2.2. Ammunition

Hunters gave detailed information on the ammunition and the rifle used as well as the shooting distance using a standardised shooting report. Bullets were classified on the basis of manufacturers' information and the evaluation of radiographs of shot wildlife (Cornicelli and Grund, 2008; Hunt et al., 2006, Trinogga et al., unpublished data). Bullets were assigned to three different classes according to their terminal ballistic behaviour: type 1 were lead-free deforming bullets, type 2 were lead-free partially fragmenting bullets and type 3 were bullets containing one or two lead-core(s). Ballistic data such as bullet mass and bullet velocity at different shooting distances were provided by bullet manufacturers. If available, information on impact energy was directly taken from these data. Otherwise impact energy (with units J) was calculated as $E_{kin,i} = (1/2000)\ mv_i^2$ with m being the bullet mass (with units g) and v_i being the impact velocity (with units m s^{-1}) at the relevant distance. Information on shooting distances was given in the hunters' reports using the following categories: up to 50 m, 51 to 100 m, 101 to 150 m, 151 to 200 m, and 201 to 250 m. For calculating $E_{kin,i}$ the upper limit of the indicated distance interval was used. Sectional density was calculated from manufacturers' data as $SD = m/A$, m being the original bullet mass (with units g) and A being the cross sectional area of the undeformed bullet (with units mm^2) in direction of flight. A was calculated as $(d/2)^2\ \pi$ with d being the bullet diameter (with units mm). Eight different brands were tested (Table 1).

2.3. Computed tomography

We conducted CTs of the shot wildlife bodies using a 4-slice-spiral-CT scanner (Lightspeed QXi, General Electric Medical Systems, USA) and the workstations ADW 4.2 and 4.4 (General Electric) and Vitrea (Toshiba, Japan). Data were acquired with a collimation of 4×1.25 mm. The analysis of the wound channel included the shot