Article

Physical Hazards in *Aepyceros melampus* Carcasses Killed for Meat Purposes by Aerial and Thoracic Shots

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Abstract: Physical hazards, such as bullet particles and bone fragments, in wild meat could be introduced by processes applied whilst killing game meat animals. These hazards may pose a health risk to non-suspecting consumers and must therefore be identified, evaluated and removed from meat and meat products. The extent of dispersion of these hazards in carcasses has not been sufficiently investigated with respect to game meat safety. This study aims to describe and quantify the occurrence of these hazards in animals shot by aerial (helicopter) shotgun targeting the head and higher neck region (n = 12) and single-projectile/free-bullet rifle shots targeting the thorax region (n = 36) of impala killed for meat consumption. To quantify the occurrence, particle sizes and dispersion surface of bullet fragments and bone splinters in the forequarters, radiographs were taken from top to bottom (dorsal ventral) and from the side (lateral) in the sequence of the skull, neck and forequarters. A $t$-test ($p < 0.05$) was conducted to compare the association of averages from the killing methods with the occurrences of bullet fragments and bone splinters. Bullet particles and bone splinters of significant sizes were introduced by the killing methods adopted. The results show a high incidence of harmful bullet particle and bone splinter sizes from the rifle thorax shots ($p = 0.005$). The dispersion of both physical hazards could cover a wide distance of >332 mm between particles on hunted game meat animals. Game meat animal killing methods with a rifle targeting the chest cavity should be refined and implemented. These should include the selection of bullets less prone to fragmentation, and compliance with regulated game meat animal-killing protocols, including regulating the placement of shots to allow only head or high neck shots for game meat animals slaughtered/culled for human consumption.

Keywords: radiography; hunting methods; physical hazards; bone splinters; bullet fragments; impala

1. Introduction

The control of physical hazards in food, including meat and meat products, remains important in ensuring food safety. Physical hazards are plastic, stones, metals, bones, wood, glass and any other foreign substance that could be found in food [1]. These foreign objects can be unintentionally introduced into food during the process of manufacturing, production, preparation or consumption, as it were, from “gate to plate” or “farm to fork” [2], or due to food tampering or intentional sabotage and; therefore, this must be monitored at all times in the food production chains. Four factors relating to physical hazards in food that cause a potential risk to consumers have been identified [3]: (1) the size of the foreign object found on/in the food product; (2) the type of the contaminated...
food; (3) the physical characteristics of the foreign object; and (4) the consumer eating the product. While the effects of physical object ingestion may vary from case to case, the risks associated with it include laceration, perforation and possible secondary infections of the mouth, tongue, gums, teeth, oesophagus and other organs of the digestive system of an exposed person [3–5]. In common with any other process of food manufacturing, game meat production could introduce similar, or more dangerous, physical hazards that must be controlled. Game animal farming, hunting and the manufacture of game meat products could introduce physical hazards at any stage of the process [6].

In the South African context, the Game Theft Act of 1991 grants ownership of game to persons who keep or hold game on land that is sufficiently enclosed [7]. This evolved into a system where game farmers would use defined breeding-intensive (animals maintained in small to moderate predator-controlled camps) and semi-extensive farming systems (larger environments to self-sustain the game population). Therefore, farmers have the right to trade, breed and harvest/hunt game animals as part of their game farm management strategies. Some of the strategies employed include the promotion of breeding for trophy hunting (horn size at a pre-determined age), and harvesting of meat from those animals that do not meet trophy standards [8]. The two most common methods used to kill game are (1) through rifle shooting during hunting or harvesting; and (2) aerial (helicopter) shotgun shooting during harvesting [9–11]. These methods utilise different calibres and bullet types. Figures 1a,b and 2a,b depict examples of the different ammunition used to kill game animals during helicopter and rifle thorax shot killing.

![Figure 1. (a,b). Shotgun cartridge (35 g; 5.2 mm pellets) used for helicopter shooting.](image1)

![Figure 2. (a,b). Bullet (30.06 rifle; 150 g) used for rifle thorax shot killing (traditional hunting).](image2)

Most hunting ammunition, including pellets used in shotgun cartridges, are made of different metals such as lead (90–95%), copper, zinc, tin and other synthetic materials to make it strong and effective for hunting and killing purposes [12–14]. Ammunition used during killing generally tends to fragment once it hits the target so as to increase the striking force whilst also ensuring that it does not penetrate all the way through the target [15]. In addition, bone splintering, classifiable as a dangerous hazard, generally occurs when the bullet/s or pellets hit the skeletal structure of the animal or as a result of an animal falling after being hit, especially when it was hit whilst in motion [16].
The prohibition of manufacturing of foodstuffs which are contaminated, impure or decayed, or are harmful or injurious to human health is advocated worldwide [17,18]. The control and monitoring of physical hazards in game meat processing is not well-developed, implemented or documented in developing countries [19]. Legislation specifically aimed at the identification, evaluation and control of physical hazards in game meat, and game meat products are lacking, even in countries that are extensively producing and exporting game meat and game meat products, such as South Africa and Namibia, although guidelines and veterinary procedure notices for the hunting of game meat animals from both countries state that only head or high neck shots may be allowed for the export market, after being slaughtered at a government-registered facility [20–23]. These guidelines are only applicable to the export market, and their focus is only on minimising contamination and not on the monitoring of physical hazards in game meat in general. The paucity of these physical hazard limits in developing countries means enforcement can only be benchmarked with guidelines from developed countries. There is a general consensus amongst countries’ food safety organisations, such as Australia’s Food Standard Australia New Zealand [24]; Canada’s Canadian Food Inspection Agency [25]; Codex Alimentarius Commission [26]; EU countries’ EU Regulation [27]; the Republic of China’s regulations [28] and the U.S. Food and Drug Administration [29], that objects in food 2 mm or larger can be dangerous to the consumer. In addition, importing countries and local customers require independently assessed compliance with internationally recognised food safety management standards such as ISO 22000:2018 [30]. This places the onus on the production and manufacturing industry to ensure that the possible presence of food safety hazards in processes and end products are identified, assessed and controlled to reduce or eliminate risk to consumers [30,31]. In order to achieve this, an organisation must have a good understanding of the presence of possible hazards associated with the production processes.

In support of this mandate, this study evaluates the occurrence, particle sizes and the dispersion surface of bone splinters and bullet fragments in a commonly hunted African ungulate species, the impala (Aepyceros melampus) (similar in size to medium-sized deer species) as derived from rifle shots targeting the thorax, and aerial (helicopter) shotgun shots targeting the head and neck. This will not only guide the game meat industry and authorities on the safety of such meat but can also give an indication of the extent of physical hazards that can be expected during meat inspection. This will also assist with possible mitigating measures that must be considered by meat safety authorities when handling the carcasses of animals killed by these processes.

2. Materials and Methods

The impala were shot as part of the normal management strategy to remove sub-par animals that did not meet the breeding criteria (horn size or colour) by one proficient hunter at the same game farm located in the Mokopane region of South Africa. The killing was carried out with a 30.06 rifle (150 g Nosler Accubond points) targeting the thorax (n = 36) and aerial (helicopter) shotgun (12-gauge, 35 g cartridges with a diameter of 5.2 mm per pellet, firing 44 pellets per round) targeting the head and neck (n = 12). The approximate distances for rifle shots ranged between 40 and 100 m and shotgun shots ranged between 15 and 20 m high. After being shot, the animals were exsanguinated before being transported to, and processed for meat in, a registered farm abattoir with abattoir registration number “2/4G” [21]. To quantify the occurrence, particle sizes and the dispersion surface of bullet fragments and bone splinters in the forequarters, 18 carcasses from the rifle-killed carcasses, and all 12 of the shotgun-killed carcasses, were selected and subjected to X-ray imaging. For each carcass, radiographs were taken from top to bottom (dorsal ventral) and from the side (lateral) in the sequence of skull, neck and forequarters (shoulder, thoracic spine and upper ribs).

The radiographs were performed with a Schimadzu UD150L 40E X-ray tube and Bucky unit and processed with Fujifilm computed radiography (CR)-IR348CL system. In this regard, no specific research criteria are applicable. The mentioned radiographic
X-ray equipment is mainly used for human radiography. However, the same equipment can also be utilised as standard imaging equipment for animal applications [32]. The researchers adapted the exposure factors and radiographic positioning criteria, from the standard protocol for human beings to align with requirements for this research project. Thus, pilot radiographic images taken of the first carcass to establish the optimum exposure technique, which was to use the 60kVp middle chamber automatic exposure device, and the focus-to-receptor distance (FRD) or source-to-image distance (SID) was set to 115 cm. Basic radiographic collimation was applied to increase image quality. All technical factors mentioned were utilised for all imaging purposes. A standard look-up table on the CR system provided optimum diagnostic viewing quality of the radiographs [33,34]. For standardisation, the terminology of SID was utilised. All radiographic images taken were analysed by IQ-lite version 2.8.0 INT EN 001R software generally used for radiography image analysis and interpretation, and subsequently, the size (length and width) of bullet fragments and bone splinters as they appear on the images were measured [32,35].

To ensure correct measuring and recording of hazard sizes, magnification was factored in with all measurements used for statistical analysis (Figure 3). The actual measurement of a standard anatomical lead marker (token) that was placed on the X-ray table next to the carcass was measured before imaging (2.5 cm), followed by measurement of the same anatomical marker on the X-ray image (2.64 cm). Formulas used to calculate the percentage of magnification were [36]:

\[
\frac{IS}{OS} = \frac{SID}{SOD} \\
2.64 \text{ cm} / 2.5 \text{ cm} = 115 \text{ cm} / SOD
\]

\[
SOD = 108.9 \text{ cm}
\]

\[
\text{Magnification factor} = \frac{SID}{(SID - SOD)} = \frac{SID}{OID}
\]

\[
\text{Magnification factor} = \frac{115 \text{ cm}}{(115 \text{ cm} - 108.9 \text{ cm})} = 1.056
\]

\[
O\%MF = \left(\frac{IS}{OS}\right) / OS \times 100
\]

\[
O\%MF = \frac{2.64 \text{ cm} - 2.5 \text{ cm}}{2.5 \text{ cm}} \times 100 = 5.6\%
\]

IS = Image size  
OS = Object size  
SID = Source to image distance  
SOD = Source to object distance  
OID = Object to image distance  
O%MF = Object % of magnification

![Figure 3. Illustration of the SID and SOD. IOD is the distance between the object and the image receptor [34].](image-url)
Therefore, 5.6% was deducted from fragment sizes after correction; fragments below 2 mm were not considered as harmful and therefore not counted. These bullet fragments may not be regarded as a physical hazard; although they are not part of this discussion, they still pose a great risk of chemical contamination of the meat and meat products. To determine the effect on meat, the dispersing surface of bone splinters and bullet fragments was also measured vertically, from top to bottom, and horizontally, from left to right, for the forequarter X-ray images.

A t-test (p < 0.05) or a chi-square test was conducted to compare the association of averages from the killing methods and the occurrences of bullet fragments and bone splinters. Data were analysed using GenStat 64-bit Release 20.1 statistical software (VSN International Ltd.).

3. Results

The forequarters of the selected carcasses were exposed to X-ray photons during imaging to quantify the occurrence, particle sizes and the dispersion surface of bone splinters and bullet fragments. Out of all impala killed, the average age was 20 months (rifle thorax shots) and 36 months (helicopter shots), and the average weight before dressing was ±40.1 kg (rifle thorax shot) and ±44.1 kg (helicopter head and neck shot). Regarding sex, 40% of the total carcasses were males (culled due to horns not meeting breeding criteria), of which all were derived from helicopter shots, and 60% were females (culled as they did not meet colour selection criteria), of which 27% were derived from helicopter shots and 33% from rifle thorax shots.

3.1. Impact and Dispersion of Physical Hazards

Regarding animals shot by rifle, 61.1% were shot from the left to the right of the animal and the remaining impala were shot from the right to the left of the animal. In 72.2% of cases, the bullets entered and exited on the opposite side of the body after fragmenting, while in 27.8%, the bullets did not exit the body and were found during dressing, meat inspection or subsequent X-ray imaging of the carcasses. None of the helicopter gunshot pellets exited the body, although it was not possible to determine how many pellets completely missed the target. Figure 4a,b shows the bullet particle distributions from the two killing methods.

![Figure 4](image_url)

Figure 4. Helicopter head and neck shots and the distribution of pellet: (a) Lateral skull projection and (b) lateral shoulder projection. Rifle thorax cavity shots showing the distribution of bullet fragments: (c) lateral thoracic spine projection and (d) lateral cervicothoracic junction projection.

Although the majority of the pellets from the helicopter head and neck shots tended to be focused in the head and higher neck region, 42% of carcasses were found to have shotgun pellets on the lower neck and thoracic parts of the body. With the rifle thorax shots, bullet particles had a wider distribution and were found on surfaces away from the entry point. Bone splinters tended to group around the shattered bone. As a result, there was no...
clear recording of the distribution pattern of bone splinters resulting from the rifle thorax cavity shots and helicopter head and neck shots. From the evaluation of the dispersion of bullet fragments, Figure 4a–d depicts the dispersion and distribution of hazards in carcasses from bullet fragments and bone splinters produced by the two killing methods. The results capture the surface covered by bullet particles vertically from top to bottom and horizontally from left to right of the entry point, as well as bone fragment dispersion. For helicopter shots, carcasses with bullet particles and bone splinters vertically from top to bottom and horizontally from left to right ranged across three categories of 0–99 mm (3 and 8, respectively); 100–199 mm (4 and 3, respectively) and over 200 mm (5 and 1, respectively). The sizes of bone fragments in these categories were: 0–99 mm (10 and 10, respectively); 100–199 mm (1 and 1, respectively) and over 200 mm (1 and 1, respectively).

A strong correlation between the occurrence of physical hazards within the specified categories is noted (chi-square = 13.2258, p = 0.040). For the rifle thorax shot carcasses (n = 18), bullet particles (vertically top to bottom and horizontally left to right) for the three categories are: 0–99 mm (14 and 13, respectively); 100–199 mm (12 and 13, respectively) and over 200 mm (5 and 4, respectively). Bone fragments are: 0–99 mm (14 and 13, respectively); 100–199 mm (3 and 3, respectively) and over 200 mm (1 and 2, respectively) (chi-square = 36.6637, p = 0.00001).

3.2. Particle Sizes of Bone Splinters and Bullet Fragments

Table 1 depicts the differences between the two killing methods in the sizes and numbers of bullet fragments and bone splinters, counted according to the physical hazard size requirements of Australia and New Zealand, Canada, the Codex Alimentarius Commission, European countries, the Republic of China and the United States of America.

| Size (mm) | Rifle (n = 18) | Shotgun (n = 12) |
|----------|---------------|-----------------|
|          | Bullet Fragments | Bone Splinters | Pellet Fragments | Bone Splinters |
| 2–6      | 58            | 7              | 44              | 11            |
| >6–25    | 7             | 38             | 6               | 3             |
| >25      | 1             | 9              | 0               | 3             |
| Total    | 65            | 54             | 51              | 17            |

In helicopter killing, no bone splinters were observed on the carcasses other than on the upper neck surfaces. Using the LSD post hoc test, the number of bullet fragments and bone splinters counted per size category differed, where the rifle-killing occurrence of bullet fragments and bone splinters also differed (LSD p = 0.00012), as well as for shotgun killing (LSD p = 0.000059) as depicted in Table 1. In both killing methods the occurrence of both hazards between the two killing methods across the different categories of hazard sizes were different, thus suggesting a strong relationship between the occurrence of bullet fragments and bone splinters from both killing methods.

4. Discussion

During game harvesting, which forms part of game farm management on commercial game farms, game animals are killed in large numbers. Older and larger male animals were targeted in this investigation as these are typically removed for effective game farm management [37–39]. While these processes are taking place on game farms, where animals are moving freely, the welfare of targeted animals should always be considered; therefore, in this scenario, a fast and efficient killing method should be used [40,41].

This investigation showed that the presence of bullet fragments and bone splinters of unsafe sizes in impala meat results from both killing methods. These hazards were also noted in earlier studies [42] as the most common physical hazards in game meat animals. A
number of studies documented the method of game meat animal killing, the size of bullet fragments left on carcasses and the resultant bone splinters as major health hazards when meat is consumed by unsuspecting consumers \[16,43\]. These killing methods therefore remain a threat to the production of safer wild ungulate meat \[44\].

Regarding dispersion of the surface bullet/bone fragments, it was observed that the helicopter head and neck shots had a narrow vertical shaped impact zone, which was smaller than that of the rifle shots. This can be ascribed to the fact these shots were from above and due to the shape of the head/neck. Radiographic images showed that, although helicopter shots generally targeted the head, pellets could be found on other surfaces such as the lower neck joining to the body, a portion generally consumed as part of a stew \[45,46\]. In contrast to gunshot pellets, some rifle bullets entered and exited the body, leaving a trail of destruction with metal fragments and bone splinters in the process \[47,48\]. Bullets that did not exit split into smaller fragments, of which some were larger than 2 mm, thus causing a physical hazard of concern to consumers, with the potential to cause significant harm \[49\].

Aggravating factors include fragments that could (1) spread to surfaces not normally associated with the kill zone and the bullet’s trajectory \[2,4,50\] and could thus be missed during the meat inspection process; (2) be undetected and missed during normal meat inspection due to their size and colour \[51–53\] and, subsequently, (3) be left inside carcasses destined for further slaughter and potentially processed \[16,54\].

To minimise risks to the consumer, improved slaughter and meat inspection methods should be followed. These measures need to be integrated to ensure or facilitate the promotion of “one health” for game meat production from farm to fork \[55\]. As copper- and nickel-made bullets have a greater tendency to fragment \[15,52\], bullets used for killing of game should be selected based on their ability to stay intact even after hitting the target \[56\]. Head and neck shots may also be a better option than thorax shots due to the fact that the head and neck can be more easily separated from the rest of the carcass, thereby minimising wastage and increasing carcass yield \[57,58\]. During primary meat inspection (PMI), physical hazards can be minimised or removed by the trimming of affected parts \[59\].

The results indicate that, for helicopter shot animals, most of the carcasses had bullet particles displaced between 30 and 225 mm from the point of impact/entry on the carcass, whilst 17% of carcasses had bullet particles in excess of 226–337 mm from the point of entry (Figure 5b). Though different from the helicopter killings, the majority of the dispersion in rifle thorax shot carcasses was between 30 mm and 332 mm from the point of entry (Figure 5a). The results of this study confirm findings \[58\] that, depending on the placement shot and the type of bullet used, a radius of up to 340 mm should be examined and may need to be trimmed to remove any bullet particles from a thoracic killing shot. This could be difficult to achieve with the current meat inspection program in South Africa and Namibia, especially at game animal slaughter facilities, where the detection of metals during the secondary dressing of game animals generally depends only on meat inspection \[50–52\]. Trimming will not only lead to a loss of money due to the significant volume of meat that will be removed from each carcass suspected of being contaminated, but it will also reduce the general appearance and value of the carcasses.

In addition, meat inspectors and slaughter operators should be trained to ensure that they are sufficiently skilled in using the available technologies that could be implemented for the purpose of identifying physical hazards during slaughter \[60\]. To aid meat inspectors and slaughter operators, metal detectors, near-infrared spectroscopy (NIS) and imaging X-ray equipment can be used \[52,61\]. However, the use of these methods on a routine basis in abattoirs is neither practical nor economically viable, especially in rural abattoirs that are far from the main national or provincial facilities that have these technologies.
Figure 5. The affected surface of carcasses from the two killing methods. (a) Typical helicopter kill showing pellets’ dispersion ranges (mm) from top to bottom/vertical and sideways/horizontal of the carcasses (b) and bullet particles’ dispersion ranges (mm) from top to bottom/vertical and sideways/horizontal for a typical rifle shot kill.

5. Conclusions

This study demonstrates that physical hazards can be caused by both killing methods. Regarding game meat harvesting, helicopter shots aiming for the head appear to be the most effective method for killing impala with the bulk of the pellets being concentrated around the head and upper neck areas, resulting in easy control/removal during meat inspection as well as minimising financial loss due to these regions being of low value. Though helicopter shots show fewer pellets in other areas of the body, it can never be guaranteed as animals are normally shot in motion and other bones of the body could fracture as a result of an animal falling after being shot. Rifle shooting aiming at the thorax, which is the hunting method followed by most hunters, shows that a large surface around the entry and exit wounds could be contaminated, mainly with bullet fragments but also with bone splinters located around any fractured bone. Due to the uneven distribution of bullet fragments, an area with at least a 340 mm radius around the bullet holes should be examined to identify and remove physical hazards that could cause harm to consumers. To promote stakeholder involvement, the immediate suggestion is to promote the training of hunters in the selection of bullets that fragment less and hunting skills that will focus on head and neck shots rather than thorax shots; the enforcement of game meat animal killing plans that are acceptable and will render instant killing with less contamination of the carcass; and to teach slaughter operators and meat inspectors specific skills of inspection methods enabling them to identify bullet particles and bone splinters.

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Informed Consent Statement: Not applicable.
Data Availability Statement: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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