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REVIEW ARTICLE

A Review of Firearms, Projectile and Gunshot Wounds in Animals

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ABSTRACT

Uses of small firearms inflict gunshot wounds posing a risk to the health and life of animals. Different aspects associated with the evaluation and treatment of gunshot wounds, therefore, must be known by veterinarians. Due to the fact that gunshot wounds are received by soldiers on battlefields, saving the injured and treatment of such wounds is usually in the realm of battlefield medicine (field surgery). Despite, extensive experience gained during military conflicts and numerous criminal events, the investigation of factors affecting gunshot wounds have recently aroused much controversy. It has been attempted to elucidate and evaluate the complexity of bullet-organism (human or animal) interactions based on numerous experiments involving shooting materials that mimic live tissues and organs, human cadavers or live animals. Even though a series of these experiments has confirmed the complexity and unpredictability of each shot, many publications, as indicated in the present review, contained numerous errors and distortions which could not be confirmed in reliable experiments and *in vivo* observations. These errors are often copied unquestioningly by authors of other publications. As veterinarians are forced to gain knowledge on gunshot wounds mainly from human medicine literature, this review attempted to compile the major subjects on gunshot wounds in animals.

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INTRODUCTION

Modern firearms, especially small arms, are becoming increasingly widespread and access to firearms has resulted in increasingly frequent cases of illegal shooting incidents involving animals. Projectiles fired with small arms can inflict injuries that pose a risk to the health and life of wounded individuals (Ball *et al.*, 2013).

Firearms are used, legally or illegally, in hunting in a manner aimed at killing an animal as quickly as possible. Other circumstances involving shooting at animals are still infrequent. Therefore, the subject of gunshot wounds is poorly understood by veterinarians. The evaluation of these specific injuries is difficult and requires a thorough approach towards each wound. The importance of this subject area makes it necessary to train veterinarians more extensively in the subject. Shooting at animals, except for cases specified by hunting laws and the right of self-defence, is always an act that infringes the law. Evaluating such cases requires a veterinarian to correctly assess not only gunshot wounds, but also the circumstances associated with a shooting. In such cases, an accurate interpretation requires a good understanding of ballistics.

Over 25 years have passed since studies on terminal ballistics were carried out by Lindsey and Fackler (Lindsey, 1980; Fackler, 1996). Despite small arms being commonly used, these problems still arouse controversy and are too often presented inconsistently with reality (Golec and Czyrny, 1997; Bartel, 2003; Houszka, 2005; Nozdryn-Płotnicki *et al.*, 2005; Dicpinigaitis *et al.*, 2006). In many publications, the matter had been discussed without confirmation of reality and often indicated a misunderstanding (especially terminal ballistics) (Swan *et al.*, 1983; Swan, 1984; Szponder, 2002; Bartel, 2003). This has resulted in veterinarians becoming over-reliant on the literature regarding gunshot wounds in humans, although gunshot wounds in people and animals often differ. The vast majority of gunshot wounds in humans are inflicted during military activities (with the use of weapons and full metal jacket ammunition) or police duty (with the potential use of different types of ammunition) and a minority result from illegal shootings like criminal actions or accidents (Carroll *et al.*, 1973; von See *et al.*, 2009; Felsmann *et al.*, 2012; Ball *et al.*, 2013). Shooting at animals is predominantly performed during hunting (with the use of guns and ammunition designed to kill immediately) (Szyrkowiec, 1988; Houszka, 2005; Rosenberger, 2009). A few gunshots are a result of illegal activities (such as poaching). Saving the life of humans shot with small arms and treating gunshot wounds is a special realm of surgery described as battlefield medicine or surgery (Carroll *et al.*, 1973; Swan *et al.*, 1983). Wounded animals are handled differently: the wounded are killed as soon as possible and a minor fraction that are shot under different circumstances are treated (Houszka, 2005; Haag, 2013). In addition, according to the international conventions, the ammunition used against humans should allow an injured person to survive, yet hunting ammunition has a completely different construction to enable killing an animal as quickly as possible (Szyrkowiec, 1988).

By investigating the practical and theoretical aspects of gunshot wounds in animals (Felsmann *et al.,* 2012) and considering publications containing information that is inconsistent with reality and diverging from the experimentally-confirmed facts (Golec and Czyrny, 1997; Szponder, 2002; Houszka, 2005; Nozdryn-Płotnicki *et al.*, 2005; Rahman *et al.,* 2011), the authors have analysed the basic problems related to gunshot wounds in animals.

Weapons: A firearm is a type of ranged weapon which uses the energy of gases generated by combusting a ranged charge (gun powder) to launch and accelerate a projectile. The authors focused on one type of such weapon: small arms with calibres up to 20 mm as, in practice, veterinarians treat gunshots from these weapons. Small arms also include pneumatic weapons (commonly known as air guns) in which a projectile is fired using compressed gas (air or carbon dioxide).

Small arms can be divided (although such divisions are conventional) based on different criteria. Considering the needs of veterinarians, it is sufficient to discuss the rules that are important for inflicting gunshot wounds and for evaluating a shot based on ballistics. Based on the length of their units, small arms include handguns (pistols and revolvers) and long firearms with lengths of over 60 cm (carbines and rifles) (Anonymous, 1991). In addition, based on the type of barrel, there are guns with smooth and rifled barrels (Szyrkowiec, 1988). These divisions also apply to pneumatic weapon. Based on their users, small arms can be divided into military (battlefield), hunting, sporting and civil weapons. It should be noted that different varieties of ammunition can be used in almost each unit of weapon. This is most often associated with the possibility to use differently-constructed projectiles (Fig. 1a).

The commonly-accepted division of weapons based on the basic parameters is important for evaluating gunshots in animals and it is thus necessary to briefly characterize the different varieties. Handguns are used to destroy targets at short distances and they must be relatively light and with limited dimensions (small barrel length) (Urley, 1989; Anonymous, 1991).

These construction requirements allow to distinguish some typical characteristics of injuries inflicted by gunshots with such weapons. Since projectiles fired from pistols and revolvers have a relatively low initial velocity, bullets with relatively large diameters (calibre) are used to generate adequate kinetic energy (Fig. 1f). The ammunition for handguns differs from ammunition for long firearms. The small overall dimensions of pistols and revolvers force constructors to use proportionally smaller bullets and that is why pistols and revolvers have limited efficacy in shooting at long distances. A loss of velocity in advance movement (with an exponential loss of kinetic energy) makes it difficult to maintain the stability of a projectile which decreases with distance. A small-ranged charge powering a relatively massive projectile with low velocity (220-430 m/s) explains why the injuries inflicted with this type of weapon are less severe when shot at long distances in comparison with wounds caused by shooting at short distances (Urley, 1989; Gugala and Lindsey, 2003). The use of handguns facilitates shooting at short distances, including point blank shots (Urley, 1989; Dicpinigaitis *et al.*, 2006).

Long firearms (carbines and rifles) can fire projectiles with high initial velocity (700-1100 m/s) and better stability while travelling to a target (Eardley *et al.*, 2013). It may seem paradoxical that high velocity projectiles fired from long firearms may inflict injuries that are much less severe than those inflicted with a handgun (Felsmann *et al.*, 2012).

Modern military weapons, both handguns and long firearms, are adapted for full metal jacket and total metal jacket projectiles, as governed by the Hague Convention of 1899. These weapons, sometimes with appropriate modifications, are used by the police and security services. The police and security services may use special weapons and special ammunitions, including those similar to hunting ammunition. Hunting guns use different types of ammunition (Fig. 1a-e). Civil weapons include the units used by private persons or representatives of organizations and companies. They serve to protect property and life and are modelled after military weapons. It should be added that many people today also own collector's weapons and replicas of black powder guns. Consequently, it also happens that animals are shot with such varieties of weapon. Criminal activities are not regulated by any rules and it should thus be considered that there is also the possibility of animal shootings involving adapted or home-made weapons.

The arrangement and number of barrels in combined weapons or the other construction elements of individual weapon types and units do not have a major impact on gunshot wounds (Szyrkowiec, 1988; Hogg, 1994; Rosenberger, 2009). Despite access to technical and tactical information on the types of small arms and the properties of individual constructions, many authors do not include the parameters of individual weapon units in their publications, either overestimating or not considering some of them (Feuchtwanger, 1982; Golec and Czyrny, 1997; Olczyk and Galbfach, 1998; Houszka, 2005; Nozdryn-Płotnicki *et al.*, 2005; Rahman, 2011). It should always be borne in mind that a projectile travelling to a target decelerates, which means that, when hitting a target, projectiles of different types of weapons may have the same velocity. Therefore, the discharge velocity of a projectile should not be regarded as the only exponent of its destructive power (Cooper and Ryan, 1990; Hollerman *et al.*, 1990a; Fackler, 1996; Silvia, 1999; Bartlett *et al.,* 2000; von See *et al.,* 2009; Alexandropoulou and Panagiotopoulos, 2010).

It therefore, seems that there is a misunderstanding in providing such information as the division of guns into: *"...manual firing rocket missiles (e.g. automatic pistols)"* or *"…laser (e.g. pistols, rifles)"* (Nozdryn-Płotnicki *et al.,* 2005). Missiles are constructions that are much larger than pistols and rifles and require special installations (launchers). Laser weapons (currently at the stage of testing as installations assembled on ships and vehicles) are not a type of firearm and giving rifles and pistols as examples is erroneous (Nozdryn-Płotnicki *et al.,* 2005).

Ammunition and projectiles: Many varieties of ammunition can be used in specific types of weapons (Fig. 1a). A single ammunition unit, i.e. a bullet, is composed of a shell which contains ranging material and a projectile embedded in the upper part of the shell (Fig. 1a & 1b). The construction of the shell and the type of ranging charge are not so important for inflicting gunshot wounds. The shell allows for identification of the type of weapon and even its specific unit. The identification of a gun based on shells and projectiles is, however, comprised by medical jurisprudence (Hayes *et al*., 2007). The knowledge of varieties and constructions of projectiles is essential for evaluating the types and extent of injuries inflicted by firearms. A projectile fired to a target in order to cause a certain reaction (destruction, injuries) is constructed for specific needs according to legally-enforced limitations (Fig. 1a-f). The broadest division of projectiles is related to the type of barrels in small arms. The projectile for guns with rifled barrels may be jacketless (Fig. 1b) or with a jacket (outer shell) made of plastic-metal alloys (Fig. 1a, 1d & 1e). The outer coat (jacket) may cover the whole projectile, i.e. Total Metal Jacket (TMJ), or may not cover its back side, i.e. Full Metal Jacket (FMJ): Fig. 1a (the projectile at the bottom) and Fig. 1d (the first two projectiles on the left). If the jacket does not cover the tip of a projectile it is called Jacketed Soft-Point (JSP): Fig. 1a (the projectiles of the upper two bullets) and Fig. 1d (three projectiles on the right). On the last projectile on the right, there are longitudinal slits of the jacket going from its tip, which causes a more rapid deformation of a projectile after hitting a target. Jacketed Hollow-Point (JHP) projectiles with a hollowed tip are a variety of Jacketed Soft-Point type. There is a series of modifications of JSP and JHP as well as different materials used for their construction. Nowadays, these constructions are often made of polymer elements as well as metal alloys (Fig. 1e) (Caudell *et al.,* 2012).

Pellet ammunition designed for smooth-barrel guns is a set of differently-sized balls made of lead or soft iron or steel alloys which, after being fired from a barrel, become individual projectiles with a relatively low momentum (lower for the projectiles with lower mass - calibre). These projectiles, however, when fired from a short distance cause very specific and serious injuries (Swan, 1984). It is very important to know the construction of individual projectiles for smooth-barrel guns, even though this ammunition is used less frequently. These projectiles are most often made of properly-shaped lead. There are also projectiles made of alloys of non-ferrous metals, sometimes in combination with polymer elements (Fig. 1c: the projectile in the middle). In many countries, these projectiles are called "brenneks", after Wilhelm Brenneke, one of the constructors of this ammunition) (Szyrkowiec, 1988; Rosenberger, 2009). A classical projectile by this constructor is depicted in Fig. 1c (the first on the left). The term "brennek" should not be used to describe all ball projectiles (individual) designed for smooth-barrel guns, as the differences in the construction of their individual types may be characterized with a varied interaction with the body of an animal (Rosenberger, 2009). The examples of such "balls" are presented on Fig. 1c (two projectiles on the right).

The ammunition for pneumatic guns, despite its small calibre, is also variably-sized. The projectiles fired from popular air guns may have sufficient energy to inflict fatal injuries and to penetrate the abdominal wall and the skull (Amirjamshidi *et al.*, 1997; Laraque, 2004; Mikołajczyk and Sośniak, 2005; Osemlak *et al*., 2005; Jirli and Kumar, 2006).

A specific amount of kinetic energy carried by a projectile is needed to cause certain injuries that are determined by the resistance of penetrated tissue against a projectile (Clasper, 2001; von See *et al.,* 2009). However, energy is transferred by the contact with the face of a projectile and the transient shape (surface) of the face has a decisive impact on the extent of injuries. It should be noted that blind shots (non-penetrating) pose a higher risk to the health and life of wounded individuals due to the transfer of all energy of a projectile to penetrated tissues and organs (Mendelson, 1991). Projectiles that leave the body of a wounded human or animal may transfer only a fraction of kinetic energy and, as long as they do not damage vital structures, they may cause only minor injuries (von See *et al.,* 2009; Alexandropoulou and Panagiotopoulos, 2010; Yubin *et al.*, 2010). Examples of deformed and fragmented projectiles are depicted on Fig. 1f (from the right: a deformed fragment of the core and jacket of a projectile after hitting a target; two deformed revolver projectiles after hitting a rubber wall). By definition, FMJ and TMJ projectiles should not become deformed and cause less severe injuries than the projectiles used in hunting guns. The construction of the latter is designed to inflict the most extensive injuries possible, leading to the most rapid killing of an animal.

Admittedly, such events are infrequent, but shots with training ammunition should not be overlooked. The projectiles for this type of ammunition are made of wood and polymers and, after firing, carry low kinetic energy. Finding wooden or plastic elements in the body of an animal may prove the occurrence of such a shooting. Some varieties of special ammunition also include non-penetrating projectiles that are made of polymers which cause superficial injuries, usually without disrupting the integrity of the skin.

Projectile kinetics and body interaction: Knowledge of the types of guns and ammunition as well as technical and physical properties of projectiles is required to correctly evaluate gunshot wounds in animals (Silvia, 1999; Hayes, 2007; Haag, 2013). Despite numerous observations, experiments and theoretical considerations, the literature still claims that high-velocity projectiles may cause serious injuries, especially by generating a greater temporary cavity (Owen-Smith and Matheson, 1968; Owen-Smith, 1981; Feuchtwanger, 1982; Swan *et al.*, 1983; Swan, 1984; Jakubaszko *et al.*, 1999; Szponder, 2002; Bartel, 2003; Osemlak *et al.,* 2005). Velocity as an indicator of the energy in a projectile is only one of the factors influencing the extent of injuries. This problem has been highlighted by a number of authors who have carried out studies on terminal ballistics (Lindsey, 1980; Clasper, 2001; von See *et al.,* 2009; Alexandropoulou and Panagiotopoulos, 2010; Felsmann *et al.*, 2012). They have emphasized the complexity of projectile-body (human or animal) interactions and the impact of individual projectile parameters on the type and extent of injuries to tissues and organs, while highlighting that the velocity of a projectile (especially initial speed) is not a predominant factor (Berlin, 1977; Fackler *et al.*, 1988; Cooper and Ryan, 1990; Hollerman *et al.*, 1990a; Mendelson, 1991; Fackler, 1996; Rossiter, 1996; Bowyer and Rossiter, 1997; Silvia, 1999; Korać *et al.*, 2000; Clasper, 2001; Gugala and Lindsey, 2003, Felsmann *et al.*, 2012).

As enforced by international law, only military ammunition for small arms should have a full jacket (FMJ and TMJ) and the other varieties of ammunitions do not have to meet this requirement. It should not be taken as certainty that full metal jacket ammunition inflicts only minor injuries and causes a regular and not too vast wound channel. The projectile-target (especially a live target) interaction is a very complex phenomenon with unpredictable consequences (Fackler *et al.*, 1988; Cooper and Ryan, 1990; Hollerman *et al.*, 1990a; Rossiter, 1996; Korać *et al.*, 2000; Maiden, 2009; Alexandropoulou and Panagiotopoulos, 2010; Felsmann *et al.*, 2012). The necessity to use a full jacket in military projectiles is enforced by law (Maiden, 2009). The stability of projectiles and maintaining their integrity is not covered by international law. Constructors of small arms and ammunition do not have to consider these subject areas. Furthermore, the plurality of factors impacting the stability and integrity of projectiles makes it impossible to embrace these factors in legal frameworks. The studies of Colonel Fackler (Fackler, 1996) and other researchers in terminal ballistics have proved that many projectiles, even those commonly used by the army, might undergo fragmentation or lose stability after hitting a live target, which involved serious injuries (Berlin, 1977; Cooper and Ryan, 1990; Hollerman *et al.*, 1990a; Fackler, 1996; Bowyer and Rossiter, 1997; Bartlett *et al.*, 2000; Alexandropoulou and Panagiotopoulos, 2010).

However, based on the aforementioned discussion, it should not be stated that the diameter of a wound caused by full metal jacket projectiles is slightly greater than the diameter of a projectile (Houszka, 2005) as this phenomenon does not always occur. It should be remembered that full metal jacket projectiles may also cause extensive injuries, including a wound channel with a large and irregular diameter and a vast temporary cavity (Alexandropoulou and Panagiotopoulos, 2010). On the other hand, it is not correct, as reported by some authors, that projectiles fired from military weapons at over 1100 m/sec velocity are the most destructive group (Scott, 1996; Szponder, 2002). Full metal jacket projectiles travelling at such velocity may cause extensive injuries, although only with unstable advance movement or fragmentation after hitting a target (Clasper, 2001; Alexandropoulou and Panagiotopoulos, 2010). While penetrating the soft tissues and internal organs, their passage is only slightly disrupted due to high velocity. Moreover, as explained by the rules of flow mechanics, an increase in the velocity of a projectile up to a certain level makes it possible to penetrate through the soft tissues, creating a channel with a diameter comparable with the calibre (diameter) of a projectile and without generating a temporary cavity, which is the consequence of the phenomenon called "drag crisis" (Felsmann *et al.*, 2012). The velocity of a projectile is a major component of its kinetic energy. Some authors distinguish between these two parameters and this fact should be considered in maintaining the order and clarity of the presentation. According to some authors, projectiles with high kinetic energy cause more severe injuries to the tissues and organs and are thus more dangerous to wounded individuals (Owen-Smith and Matheson, 1968; Owen-Smith, 1981; Swan *et al.*, 1983; Swan, 1984; Jakubaszko *et al.*, 1999; Szponder, 2002; Bartel, 2003; Osemlak *et al.*, 2005). These authors considered only one of the injury-inflicting factors and overlook the complexity and unpredictability of physical processes occurring when projectiles passed through the tissues of living organisms. It is enough to note that the energy of a projectile may be transferred onto the tissues that are destroyed and through which it travels only when remaining in direct (crushing, cutting, tearing apart) or indirect (a temporary cavity) contact (Hollerman *et al.*, 1990a; Fackler, 1996; Rossiter, 1996; Mendelson, 1999; Clasper, 2001; Alexandropoulou and Panagiotopoulos, 2010; Felsmann *et al.*, 2012). The laws of conservation of energy and momentum do not leave any doubt to that. Thus, the kinetic energy being directly proportional to the mass of a projectile and exponentially to the velocity, only determines the potential capacities of a given type of ammunition to inflict specific injuries. This phenomenon was observed after the introduction of full metal jacket ammunition at the end of the 19th and the beginning of the 20th century (Woodruff, 1898; Maiden, 2009). It should be noted that jacket-less projectiles of the ammunition that was commonly used in the 19th century (Fig. 1b) caused, even at a stable penetration of the soft tissues (without tumbling or fragmentation), greater temporary cavities than full metal jacket projectiles which travelled much faster. Therefore, reports on more extensive injuries caused by projectiles with higher energy as reported by Swan *et al.* (1983), Olczyk and Galbfach (1998), Jakubaszko *et al.* (1999), Szponder (2002), Bartel (2003), and Dicpinigaitis *et al.* (2006) should be regarded as erroneous. The kinetic energy of a projectile is only an indicator of the capacity to cause specific injuries. The type and extent of injuries are determined by the transfer of energy by a contact between the face of a projectile and the tissues and internal organs of a victim and, thus, cause certain consequences (Berlin, 1977; Cooper and Ryan, 1990; Hollerman *et al.*, 1990a; Molde and Gray, 1995; Rossiter, 1996; Bowyer and Rossiter, 1997; Bartlett *et al.*, 2000; Korać *et al.*, 2000; Alexandropoulou and Panagiotopoulos, 2010; Yubin *et al.*, 2010; Felsmann *et al.*, 2012).

Another misunderstanding is associated with the possible impact of a projectile on the tissues and the potential destructive influence of a shock wave elicited by a projectile travelling at ultrasonic velocity (Golec and Czyrny, 1997; Szponder, 2002; Houszka 2005). This erroneous view was presented in the 1940s by Harvey and this effect was not observed in other experiments (Hollerman *et al.*, 1990a; Korać *et al.*, 2000). One should thus remain cautious about reports on the impact of "hydrostatic shock" generated by a moving projectile on the central nervous system. The influence of this factor on dysfunctions (bleeding) in the central nervous system has been reported by Courtney and Courtney (2011).

Gunshot wounds: Inflicting a gunshot wound is a very complex phenomenon as each gunshot involves many factors, including the characteristics of guns, ammunition and the properties of tissues and organs (Clasper, 2001; von See *et al.,* 2009; Alexandropoulou and Panagiotopoulos, 2010; Tang *et al.,* 2012; Haag, 2013).

Based on their course, gunshot wounds can be divided into perforating (having an entrance and an exit), blind (penetrating; without exit) and contact (when the skin and tissues underneath are destroyed; without channel formation). A projectile creates a channel in perforating and blind wounds. This division should be regarded as conventional as it may be referred to homogenous tissues, particularly the muscles. It is difficult to distinguish the above-mentioned factors in a gunshot wound to the thoracic cavity and abdominal cavity when a projectile penetrates the internal organs. In such cases, the aforementioned characteristic of a gunshot wound would be different for each organ (Fig. 2). The channel of a wound is created by destroying (crushing, cutting, tearing and translocation) the tissues by a projectile which penetrates the body of an animal, with the face of a projectile remaining in constant contact with the destroyed structures. This stable channel remains unchanged after shooting. During penetration of a projectile through the tissues, a transient channel is formed called as a temporary cavity. The entrance of a wound (which is sometimes called an entrance wound) caused by single stable projectiles fired with small arms, is regular with smooth margins and, depending on the area and entrance angle, is round-to-elongated ellipse or oval (Fig. 2 a). The entrance (entrance wound) is characterized by a number of features that distinguish it from the exit opening (e.g. laceration edge, singe edge) (Dicpinigaitis *et al.*, 2006). In the case of shots perpendicular to the body surface, the diameter of the entrance may be both slightly larger and slightly smaller than the diameter of a projectile. The diameter of the entrance of a wound is usually smaller than the exit (the surface of both openings should be compared more precisely) (Fig. 2a & 2d). The exception is when a projectile enters at a sharp angle to the body surface (an opening that resembles a contact wound) and it exits without deformation at an approximately right angle. Another case is the formation of the exit only by a fragment of a projectile which has

Fig. 1: Ammunition for small arms: a – bullets, calibre 30 06, with different projectiles: a FMJ at the bottom and two JSP above; b – a jacket-less projectile of old type; c – ball ammunition for smooth-barrel guns; d – projectiles for hunting guns; e – a JSP with the element made of polymers in the top segment; f – ammunition for handguns, from the left: two bullets for pistols, the first one with a cross-section of a projectile, a shell of a revolver bullet, and three deformed projectiles. Scale: one square = 0.5 cm. Figure from authors collection.

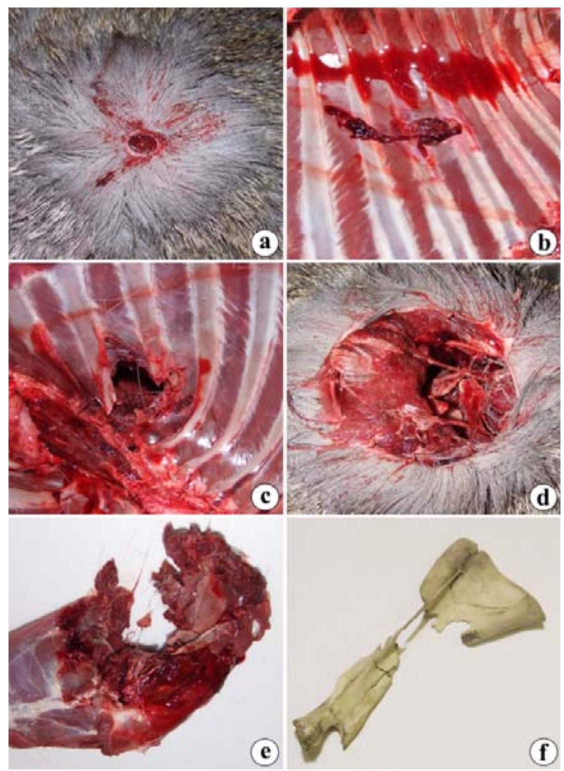

Fig. 2: The effects of a projectile penetrating the thoracic cavity in a roe deer (a JSP projectile of 30 06 calibre): a – entrance wound in the skin; b – entrance wound seen from the inside of the thoracic cavity; c – exit wound seen from the inside of the thoracic cavity; d – exit wound seen from the outside; e – left limb after being separated from the body; notice the injuries to the muscles, tendons and the scapula; f – damaged scapula, dissected and partially reconstructed from the fragments left in the body. Figure from authors collection.

fragmented during penetration. In addition, one should consider different sizes and shapes of exit wounds, especially in the skin (Druid and Ward, 2000; Hayes, 2007). Although the diameter of a wound channel is always greater than the diameter (calibre) of a projectile which inflicts injuries, the diameter of a channel may be different even in gunshots with the same type of projectiles (Alexandropoulou and Panagiotopoulos, 2010).

Gunshot wounds as complex and individual phenomena have, in some aspects, common or at least comparable features. Many common, even identical, traits can be distinguished in the entrance openings of wounds inflicted by gunshots at short ranges including point blank shots. The features of these wounds that are easily noticed in humans, may not be fully displayed or only partially displayed in animals. This fact is explained with the presence of a hair coat in animals (Dicpinigaitis *et al.*, 2006). A thick hair coat may prevent deformation (mushrooming) of Jacketed Soft-Point projectiles, which results in injuries resembling those caused by Full Metal Jacket projectiles (Urley, 1989). The exit openings of gunshot wounds are less characteristic, yet are still determined by the type of a projectile, its deformation and location of the gunshot (Druid and Ward, 2000; Dicpinigaitis *et al.*, 2006).

The injuries caused by multiple projectiles (pellet bullets) fired at close proximity also have their specificity and have been compared to wounds inflicted by a shark (Swan, 1984).

During penetration by a projectile, a phenomenon occurs concentrically around it – it is called a temporary cavity. A conglomerate of the body fluids, solid particles, destroyed tissue and gases through which a projectile travels is formed at the face of a projectile. As a result of this movement and a variety of physical processes related to the flow mechanics, the elements of tissues destroyed by a projectile are thrown aside perpendicularly to the axis of a projectile's trajectory. The dynamics of this phenomenon depend mainly on the temporary shape of the face of the projectile. The formation of a temporary cavity obviously requires high kinetic energy carried by a penetrating projectile (Felsmann *et al.*, 2012).

In a gunshot wound and around its channel, three zones can be distinguished (Olczyk and Galbfach, 1998). The first one is an area surrounding the channel, which is composed of necrotic tissues, thrombi and elements carried by a projectile. The second zone is located deeper and is an area with microscopically-observed vascular lesions (petechiae, passive hyperaemia) which undergo necrosis. The third zone is an area of lesions at the functional level that are noted microscopically (Olczyk and Galbfach, 1998). This division is conventional and modified by many different authors. It is important to correctly identify these zones, especially the last one, as functional disturbances in the outer zone often regress spontaneously (Ziervogel, 1979; Felsmann *et al.*, 2012).

A number of authors have confirmed the complexity and unpredictability of the phenomenon of a temporary cavity based on personal observations and experiments on models and animals (Cooper and Ryan 1990; Hollerman *et al.*; 1990a, Fackler 1996). These facts have been overlooked or ignored by some researchers, who insisted that the formation of a temporary cavity, especially its size, mainly depended on the velocity of a projectile (Dicpinigaitis *et al.*, 2006). Furthermore, they reported exaggerated unconfirmed information (either intravital or experimental) on the size of a temporary cavity, i.e. even 300 times bigger than the diameter of a projectile (Golec and Czyrny, 1997; Olczyk and Galbfach, 1998).

Ultra-fast cameras enable us to follow a projectile both on-route to a target and inside a target (gelatine blocks). However, the authors firing on targets simulating the body of a living organism have focused primarily on the effect caused by a projectile and have not necessarily paid attention to the temporary shape of the face of the projectile (Korać *et al.*, 2000; Zhang, 2007; Schyma, 2010; Schyma and Madea, 2011). An analysis of the results of these experiments, such as photos and videos, indicated that it is not the velocity (especially at the exit), but the temporary shape of the face of a projectile which determines the occurrence and size of a temporary cavity. In the case of "tumbling", the temporary face of a projectile may be its side or back surface and, after fragmentation, a temporary surface refers to all parts of a disrupted projectile. The experiment by Yubin *et al.* is worth mentioning: it consisted of shooting dissected mandibular bones. While penetrating the flat bones, the FMT projectiles with cores made of low-carbon steel (not prone to deformation) made only a round opening in the bone without affecting the other parts. On the images taken with an ultra-fast camera, it is clearly seen that there is a lack of deformation in the face of a projectile during penetration and the measurement of the velocity of a projectile demonstrates a slight reduction after passing through a target. This experiment confirms that during a gunshot without deformation of a projectile (even for massive and resistant tissue), only a minor transfer of energy takes place, which results in minor breakages (Yubin *et al.*, 2010). A temporary cavity may be caused by the secondary projectiles: bone fragments, teeth, fragments of clothing (in humans) (Dicpinigaitis *et al.*, 1990; Hollerman *et al.*, 1990a; Rossiter, 1996). These observations confirm the phenomena described by the flow mechanics. The authors of the present publication know, from their own experience of the gunshots of animals during hunting, that the injuries to the tissues and organs confirm the complexity and unpredictability of the phenomenon of a temporary cavity. The most evident examples are cases of total destruction of the liver (fragile organ) after shots with "brennek"-type projectiles which are regarded as slow and only the clear passage, through the liver, of a JSP projectile (regarded as fast) only damaging the liver lobe (the fixed channels of the wound were slightly bigger than the diameter of a projectile) without disintegration of the organ. In the first case, a deformed projectile was left in the body of an animal (its whole energy was transferred to the tissues of the target animal). Other authors have also reported on the role of energy transfer by a projectile in causing the extent of injuries (Mendelson, 1991; Clasper, 2001). The second case is consistent with the observations by Alexandropoulou and Panagiotopoulos, (2010). An example of increasing energy transfer (as a result of deformation of a projectile and the creation of secondary projectiles) by a JSP projectile penetrating the body of a roe deer is presented in Fig. 2. An image of a lung shot through in the same animal with a distinct zone of circulatory disturbances as a result of a temporary cavity has been featured in a different publication (Felsmann *et al.*, 2012). These observations confirmed numerous case reports of gunshots with what were thought to be fast projectiles during military conflicts and criminal events (Carroll *et al.*, 1973; Pachter and Spencer, 1979). If "fast projectiles" always generated vast temporary cavities, each shot to the internal organs would result in their destruction, which applies to the liver, in particular. The possibility to treat humans with such gunshots contradicts this thesis (Carroll *et al.*, 1973; Taylor, 1973; Pachter and Spencer, 1979; Hollerman *et al.*, 1990a).

Providing information on “brenneke”-type projectiles (single projectiles for smooth-barrel guns) creating bigger entrance wounds than exit injuries and claiming that this feature is typical of this type of ammunition seems to be a misunderstanding (Houszka, 2005). Moreover, it is sometimes reported that this type of projectile becomes deformed in the body of an animal. The genesis of a gunshot wound should not be explained only as crushing and cutting the penetrated tissues or “squeezing through” while overlooking the mechanism of a temporary cavity as presented in the paper by Houszka (2005).

Management of wounded animals and wound dressing: In the 20th century, field surgery made an enormous progress in saving the injured and treating wounds. Between the First World War and the war in Iraq, the percentage of soldiers surviving gunshots and recovering increased several times (Maiden, 2009). Apart from therapies with antibiotics and other drugs and the use of previously-unknown diagnostic techniques and surgical equipment on a wide scale, this progress was much impacted by acquiring knowledge of the interactions between a projectile and a living target. The most experience was achieved during the war in Vietnam (Caroll *et al.*, 1973; Swan, 1984). Modern automatic rifles (AK 47 and M 16) firing FMJ projectiles were used on a wide scale and inflicted extensive gunshot wounds. The ammunition for both rifles met the requirements of the international law. However, a projectile fired by AK 47 was not always stable in the body of a wounded person as it “tumbled” and a smaller projectile designed for an M 16 often became fragmented in the body (Carroll *et al.*, 1973). The unstable and fragmented projectiles inflicted injuries comparable to the wounds presented on Fig. 2 e. The invention of gunshot wound treatment methods for even extensive injuries was a positive side of those events (Swan, 1984). Until today, the treatment of gunshot wounds has remained the domain of military surgeons. Therefore, it seems important to use the experience of human medicine to treat gunshot wounds in animals (Bowyer and Rossiter, 1997; Simpson *et al.*, 2003; Przystasz *et al.*, 2004; Santucci and Chang, 2004; Osemlak *et al.*, 2005; Volgas *et al.*, 2005; Dicpinigaitis *et al.*, 2006; Zhang *et al.*, 2010; Cannon *et al.*, 2011; de Oliveira *et al.*, 2014). However, this does not mean that veterinary medicine lacks its own background in this domain (Szponder, 2002; Gatineau and Plante, 2010; Nakao *et al.*, 2010; Plantman *et al.*, 2012; Baker *et al.*, 2013).

The implications of accepting unconfirmed assumptions concerning the evaluation of injuries caused by small arms should be emphasized. The above-mentioned examples such as overestimating the velocity of a projectile (its kinetic energy) as the most important factor that generates a temporary cavity has resulted in some surgeons attempting to excise the tissues around a wound channel with a wide margin as is done to treat gunshots with “fast” projectiles (Dicpinigaitis *et al.*, 1990; Szponder, 2002; Bartel 2003). Worse still, some of these authors believe that dressing a wound inflicted by “slow” projectiles does not require as much attention as with “fast” projectiles (Feuchtwanger, 1982; Dicpinigaitis *et al.*, 2006; Rahman *et al.*, 2011). The necessity of such an approach has not been confirmed by the authors of experiments on living animals or experiments on models simulating living organisms (Lindsey, 1980; Fackler, 1996; Bowyer and Rossiter, 1997; Santucci and Chang, 2004; Korać *et al.*, 2006). They emphasize that the knowledge of the type of weapon is harmful to gunshot victims, as surgeons dress wounds not based on their severity, but on the type of gun. The researchers noted that it is necessary to treat a wound, not a gun (Lindsey, 1980; Bowyer and Rossiter, 1997). The histopathological lesions observed around a gunshot wound channel as a result of a temporary cavity are not always persistent and some of them disappear (especially in the outer zone) several dozen hours after the shooting (Ziervogel, 1979). The cases reported by Rahman *et al.* (2011) on successful treatment of gunshot wounds with the methods designed to treat gunshots with slow projectiles (the author estimated the velocity of projectiles based only on the type of gun) may be thought to confirm that it is not necessary to excise the tissues around a wound channel with a very wide margin. It should be emphasized that this author expressed some doubts regarding the division of projectiles into slow and fast (Rahman *et al.*, 2011).

The presented pathogenesis of injuries inflicted during shooting implies treating each gunshot wound as a single event requiring attention regardless of being caused by a slow or a fast projectile (Hollerman *et al.*, 1990a; Bowyer and Rossiter, 1997; Silvia, 1999; Maiden, 2009; Alexandropoulou and Panagiotopoulos, 2010). This assumption should be also borne in mind for wounds by pneumatic guns (Amirjamshidi *et al.*, 1997; Laraque, 2004; Mikołajczyk and Sośniak, 2005; Jirli and Kumar 2006; Plantman *et al.*, 2012).

In treating gunshot wounds, it is essential to use diagnostic imaging techniques due to the specificity of each shot. One should consider the fragmentation of projectiles, secondary projectiles and potential contamination of a wound with the elements introduced by a projectile (Hollerman *et al.*, 1990b; Wilson, 1999; Thali *et al.*, 2003; Dulić *et al.*, 2007; Haag, 2013). Fig. 2c, 2d, 2e & 2f illustrate how the secondary projectiles (fragments of a crushed bone) are formed and what injuries they cause. The muscles and skin on the left front limb in a roe deer were partially destroyed by fragments of the scapula. Many of these fragments were torn away from the middle section of the scapula and thrown outside the body (Fig. 2f).

Antibiotic therapy and prophylaxis of infections with anaerobic organisms should be the standard, as projectiles always contaminate a wound and the conditions inside it favour the growth of pathogenic microorganisms (Simpson *et al.*, 2003; Dicpinigaitis *et al.*, 2006).

Shooting at animals as a criminal act: Each use of a gun against an animal without permission (hunting) or justification (the right of self-defence) is a prohibited act (Eliason, 2003; Faccio *et al.*, 2014; Gandiva *et al.*, 2014). Such episodes thus require a veterinarian to issue an opinion. A veterinarian acting as a court expert in the cases of shooting at animals assumes great responsibility because the stated opinion becomes legal evidence (Szarek *et al.*, 2001; Szarek, 2005; Munro and Munro, 2011; Newbery and Munro, 2011; Reddy and Lowenstein, 2011; Felsmann *et al.*, 2012). The reliability of such proof may influence the verdict of the court or a decision made by an institution (e.g. an insurance company). Publishing articles without complete and accurate interpretation of presented matters creates misunderstandings (Houszka, 2005; Nozdryn-Płotnicki *et al.*, 2005).

Although all possible circumstances of a shooting should be considered for a reliable analysis of a case, the complexity of projectile-live target interactions and the uniqueness of injuries inflicted by the same types of guns and ammunition should always be borne in mind. Proper practical and theoretical knowledge of a veterinarian acting as a court expert is always important (Urley, 1989; Druid and Ward, 2000; Volgas *et al.*, 2005; Hayes *et al.*, 2007; Nakao *et al.*, 2010; Caudell *et al.*, 2012; Cecchetto *et al.*, 2012; Sanches *et al.*, 2012; Taborelli *et al.*, 2012; Tang *et al.*, 2012; Szkoda *et al.*, 2013; Johnson *et al.*, 2014).

Recapitulation: Although the experiments and opinions of all authors of papers on gunshot wounds should be respected, the authors are nevertheless inclined to support one of the parties in this dispute. This is because observations of the variety of injuries caused even by the same type of gun and ammunition to animals during hunting does not allow their repeatability. Moreover, personal studies on the mechanism of interactions between a projectile and a live target have prompted an approach to this phenomenon as a solid body travelling in a multi-phase environment. The standard laws of physics and flow mechanics force us to assume that the interaction between a projectile and the body of a living organism (a human or an animal) is a very complex phenomenon where an outcome is impossible or, at best, difficult, to predict. Personal observations performed during hunting, necropsies of animals shot with guns and theoretical analyses, including the flow mechanics, have prompted the authors to adopt the presented unambiguous opinion. It is further justified by the fact that this standpoint is only sceptical of authors who present radical views and claim that gunshot wounds result from single, always predictable causes.

Conclusion: Each shooting should be regarded as an individual, unique case. Each gunshot wound is an injury that requires an individualized approach to treatment – the same gun and ammunition may cause completely different injuries and different types of gun and ammunition may inflict the same or comparable injuries. A veterinarian acting as a court expert evaluating gunshots in animals must have broad, unbiased knowledge and should be able to analyze each case individually without making generalizations.

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