7 Firearms and Ballistics

Rachel Bolton-King[1]* and Johan Schulze[2]*
[1]*Department of Forensic and Crime Science, Staffordshire University, Stoke-on-Trent, Staffordshire, UK;* [2]*Veterinary Forensic and Wildlife Services, Germany and Norway*

---

*Corresponding authors: r.bolton-king@staffs.ac.uk; schulze@vet-for-wild-serv.eu

Practical Veterinary Forensics (ed. D. Bailey)

7.1 Crime Scene Evidence: Firearms and Ballistics

Rachel Bolton-King

7.1.1 Introduction

Crime scenes involving shooting-related incidents can contain a raft of forensic evidence that may be of benefit to the forensic veterinarian and criminal investigating team. The nature of the firearm (Section 7.1.2) and the ammunition (Section 7.1.3) utilized in the shooting have a critical role to play in the resulting injury and trauma exhibited in the body.

The term ballistics is defined as the study of the motion of projectiles. Ballistics is divided into three main categories: internal (Section 7.1.4), external (Section 7.1.6) and terminal (Section 7.1.7); however, there is also a fourth category known as intermediate ballistics (Section 7.1.5). Terminal ballistics (Section 7.1.7) covers both inanimate objects and living organisms; however, the study of projectiles through living organisms is classified as a sub-category of terminal ballistics referred to as wound ballistics (see Section 7.2).

The field of firearms and ballistics is extensive. This chapter, therefore, aims to provide an introductory explanation of the scientific theory underpinning firearms, ammunition and ballistics. The focus will be on the common types of firearm and associated ammunition that are utilized by civilians, which would ultimately be encountered in the majority of cases where veterinarians are involved in forensic investigations. For more in-depth reading into this field, recommended reading includes Farrar and Leeming (1983), Carlucci and Jacobson (2008), Heard (2008), Haag and Haag (2011), Warlow (2011).

7.1.2 Firearms

The legal definition of a firearm differs slightly from the dictionary definition. A firearm is defined by The Firearms (Amendment) Act 1988 (UK Parliament, 1988) as ‘a lethal barrelled weapon of any description from which any shot, bullet or other missile can be discharged’; whereas the Oxford English Dictionary (Oxford University Press, 2014) simply identifies a firearm as different types of gun, i.e. ‘a rifle, pistol or other portable gun’, thus ‘gun’ is defined as ‘a weapon incorporating a metal tube from which bullets, shells, or other missiles are propelled by explosive force, typically making a characteristic loud, sharp noise’. The mechanism of firing the projectile (Section 7.1.2.2) is unspecified; however, the legal definition implies that the weapon must be capable of killing a living target. The dictionary states that an explosive force is required; however, the force may not have to be explosive in order to be lethal. The legislation around firearm ownership, transportation and use will vary extensively depending on the region in which the crime occurred.

7.1.2.1 *Types of firearm*

The term handgun is commonly used to describe any firearm that is capable of being fired from one hand (AFTE Training and Standardization Committee, 2007). This term includes two types of firearm: revolver (or revolving pistol) and pistol, although the sub-machine gun (SMG) may also be considered in this category. Within the UK, air weapons are currently the most common firearms utilized in gun crime as these are typically legal and unlicensed, but this is closely followed by handguns (Berman, 2012; Smith *et al.*, 2012) due to their small size, making them easy to conceal from other civilians and law enforcement. Air weapons are typically used for recreational use, such as target shooting, whereas handguns are typically utilized for self-defence.

The main difference between a pistol and a revolver is that a revolver has a cylinder containing multiple chambers, each capable of housing a single ammunition cartridge, and the chamber is therefore separated from the barrel. A pistol has a single chamber that houses only one ammunition cartridge and this is integrated into the barrel. A sub-machine gun is a shorter-barrelled, lightweight machine gun, designed to fire pistol-sized cartridges in short or long bursts of fire. Modern handgun barrels are typically rifled with a spiral internal surface profile consisting of alternating spiral lands and grooves to enhance the ballistic properties of the projectile upon muzzle exit. Figure 7.1.1 indicates the key components common to a wide range of firearms.

Rifles also have a single chamber to house one cartridge, but are identified by their longer-rifled barrel and are larger in overall size than handguns. Rifles are designed to be fired by one individual, but using two hands.

A shotgun is differentiated from handguns and rifles due to the smooth-bore barrel and typically utilizes cartridges measured in gauge rather than calibre. Gauge equates to the number of lead balls with the diameter of the barrel bore, that collectively weigh 1 lb. The calibre is either the internal diameter of the mouth of the cartridge case or the maximum diameter of the projectile (units may be metric or imperial). For example, a 12-gauge shotgun has a barrel diameter of 0.729 in. and 12 lead balls of 0.729 in. weigh 1 lb. Shotguns are usually single- or double-barrelled with the latter having either a side-by-side or up-and-over barrel alignment. Shotgun barrels also may contain a choke at the muzzle end, which can be integral to the barrel or be removable. The choke aims to force the multiple shot together prior to exiting the barrel and there are varying degrees of choke available. To be made more concealable, criminals are known to cut down and shorten the barrel length, which will ultimately reduce the velocity, energy and range of the projectile(s) and increase the spread of lead shot fired from the ammunition due to excessively high pressure (Haag and Haag, 2011) and choke removal.

Tasers and stun guns may also be considered as a firearm in some countries, including Great Britain. Tasers are designed to fire two barbs from a cartridge, which are connected to the weapon by wire reaching

Fig. 7.1.1. Annotated image of a Sig Sauer P226 semi-automatic pistol field stripped into its key component parts listed from top of the image; slide (containing the ejection port), barrel (with integral chamber), recoil guide spring, frame and magazine (housed inside the grip of the frame).

up to 10.6 m. When the wired barbs make contact with or penetrate the upper layer of the skin (epidermis) the electrical circuit is complete and current is passed through the target's tissue to incapacitate. Tasers can be used in stun drive mode to cause pain, whereby the cartridge is not used and contact is made directly between the skin and the electrical device.

Other weapons that could be considered relevant within the context of veterinary forensics are bows and crossbows, humane killers such as captive-bolt guns (Warlow, 2011), airsoft weapons and paintball guns. However, by the UK legal definition these are not firearms and therefore not considered within the scope of this chapter.

7.1.2.2 Modern firing mechanisms

Firing mechanisms involve the loading of the projectile/ammunition into the weapon and the functioning of all the firearm's internal components required to propel the projectile out of the barrel. Design and functionality of specific firearms is an extensive topic, ultimately determined by the firearm manufacturer. Forensic veterinarians do not need to know the in-depth details of all firing mechanisms, but need to appreciate the differences in the key firing mechanisms and how these influence the ammunition selected, the properties of the projectiles fired and the potential differences that could be expected for wound examination and interpretation.

Air weapons are relatively low-powered weapons, which use a high-pressure volume of gas, typically atmospheric air or carbon dioxide, to transfer energy to the projectile (pellet) and propel it out of the barrel; these weapons therefore do not require ignition of chemical compounds to generate kinetic energy. Air weapons using atmospheric air typically operate by manually compressing a spring; pulling the trigger releases the spring compressing the air and pushing it behind the pellet. Alternatively, the pellet is fired utilizing a small jet of compressed gas, such as carbon dioxide, released from a small gas canister attached to the weapon when the trigger is pulled. In most of the UK, the legal limits for an air weapon to be classified as a firearm are higher than 1 ft lb (Home Office, 2014). Criminal use of air weapons was on the rise until 2003/2004 (Berman, 2012), when legislation aimed to reduce this (Squires, 2014). However, injuries to animals caused by air weapons are still more commonly observed by veterinarians. To be legal and unlicensed, air pistols must generate projectile muzzle energy less than 6 ft lbs (8.1 J) and less than 12 ft lbs (16.3 J) for air rifles (Home Office, 2014). However, in Northern Ireland, air weapons firing projectiles with muzzle energy greater than 1 J must be held on a firearms certificate (Northern Ireland Office, 2005).

The ammunition is loaded into the weapon either manually, or automatically from a magazine or belt of ammunition. Automatic loading (self-loading) uses the energy created from discharging a previous cartridge to reload the next live cartridge of ammunition into the chamber ready to be fired again. Heard (2008) and Warlow (2011) discuss the range of firing mechanisms that enable self-loading of ammunition and examples include recoil, blowback and bolt-action. Principally, there are two overarching automatic firing mechanisms: semi-automatic and fully automatic. Semi-automatic means that with one pull of the trigger, one cartridge is fired. With fully automatic, one pull of the trigger causes continual firing and reloading of ammunition until either the trigger is released, or there is no ammunition left to fire from the magazine or belt. There are some firearms designed to fire short bursts of ammunition, whereby continual hold of the trigger will fire a small number of cartridges (usually three to five); to fire further cartridges the trigger will need to be released and pulled again. Modern pistols such as Browning Hi-Power and Beretta 92FS are commonly semi-automatic, whereas SMGs such as MAC-10 and Uzi SMG may also have the capability of fully automatic fire and the AK47 assault rifle may have the additional option of short-burst fire.

For handguns, there are two ways to set the trigger and fire the weapon: single-action and double-action. Single-action requires a manual cocking of the hammer and then a subsequent pull of the trigger to fire. With double-action, a longer and heavier pull of the trigger will first cock the hammer and then release the firing pin/striker on to the cartridge causing it to discharge.

For rifles and shotgun, the firing mechanisms include single-shot, bolt-action (bolt is turned to lock the cartridge into the breech end of the barrel before firing), self-loading (similar to self-loading pistols) and pump-action (breech is linked to the fore-end, which when pulled back, unlocks the breech and ejects the cartridge case; pushing the fore-end forward loads in a live cartridge from the magazine and cocks the weapon).

Other terms used to describe firearms and their firing mechanisms include converted (for example, a blank firing weapon converted to fire ammunition such as Olympic 38 or Baikal), home-made, concealed (firearms made to look like other objects such as pen gun), de-activated (firearms made unable to fire ammunition by machining/removing key components), reactivated (deactivated weapons made to fire again) and imitation (firearms that look real, but do not fire live ammunition).

7.1.3 Ammunition

Like firearms, ammunition has developed over the centuries. However, ammunition is designed first for a specific purpose; the weapon is developed later to fire that ammunition. For example, Georg Luger developed the 9 × 19 mm cartridge in 1902 which was later designed to be fired in the 1908 Luger P08 semi-automatic pistol (Jones and Ness, 2009; Bolton-King, 2012). Thus, a wide range of ammunition with a variety of specifications has been developed for specific purposes (Table 7.1.1); choosing the correct ammunition for a specific weapon can be critical to achieve the intended outcome. To ensure the weapon fires safely and correctly, the dimension(s) of the ammunition (calibre or gauge) must be accurately selected for the firearm in which it is discharged.

7.1.3.1 Composition

Modern ammunition has developed from loading individual components (primer, propellant and projectile) into a self-enclosed cartridge system to create a closed environment for a large amount of gas to be produced and allow the gas pressure to rise exponentially.

The core components of a cartridge are the cartridge case and the projectile. The projectile is positioned at the mouth of the cartridge case and they are crimped together to form the cartridge. The base of the cartridge case houses the primer unit that contains the primer compound. Inside the cartridge case, the propellant is confined between the primer unit and the projectile.

Table 7.1.1. Common examples of modern ammunition calibres and their intended purpose.

Calibre (in.)	Weapon Type (Centre-Fire)	Purpose
0.22 Hornet	Rifle	Small varmint hunting (<200 m)
0.223 Remington	Rifle	Military standard (long range)
0.303 British	Rifle	Military standard (long range)
0.357 Magnum	Revolver	Law enforcement (short range)
0.410	Shotgun	Small varmint/game hunting
0.45 Automatic Colt Pistol (ACP)	Pistol	Close combat, self-defence
0.458 Winchester Magnum	Rifle	Hunting dangerous game
Calibre (mm)		
7.62 NATO	Rifle	Military standard (long range)
9 × 19	Pistol or sub-machine gun	Military standard (short range)
Gauge		
20	Shotgun	Recommended for hunting novices
12	Shotgun	Short range bird hunting

The primer (Section 7.1.4.1) and propellant (Section 7.1.4.2) are both mixtures of chemical compounds designed to ignite, burn and provide oxygen to the combustion process. Priming compounds are typically inorganic compounds that are explosive and more exothermic, whereas propellant flakes are organic in nature, burning slower and slightly cooler.

There are two main classifications of modern cartridge: centre-fire and rim-fire. The difference is due to the location of the explosive primer that ignites the cartridge. As the name implies, the centre-fire cartridge has the primer located in the centre of the base, whereas the primer within the rim-fire cartridge has it located around the rim.

Projectiles are identified for ammunition based on the intended functional purpose of the cartridge and the weapon type the cartridge is designed for. Projectile shape, dimensions and material properties affect the external (Section 7.1.6) and terminal ballistics (Section 7.1.7) following projectile exit from the barrel. Typically the softer the material property of the projectile, the more easily the projectile will deform on impact with a target, increasing surface area and increasing the amount of energy that can be transferred into the target material. For example, a full metal jacketed (FMJ) projectile is harder than a metal jacketed hollow-point (HP) that has an exposed lead cavity at the projectile nose. The HP will deform and mushroom on impact with a target, significantly reducing penetration depth and increasing wounding in comparison to an FMJ. This makes the FMJ more suitable for military use and the HP more suitable to law enforcement and hunting, where only one target needs to be hit.

Air weapons do not utilize a cartridge system, as the compressed air supplies the force to propel a single lead pellet using comparably low gas pressure. More lethal firearms utilizing cartridge-based ammunition create much higher gas pressures during ignition, and therefore have greater muzzle velocity, muzzle energy, range and penetration depth. However, research has shown that even blank firing weapons can be fatal, due to the gas pressures released (Demirci *et al.*, 2011). Projectiles fired from pistols, revolvers, rifles and machine guns are typically referred to as bullets. Shotgun ammunition, however, commonly contain multiple spherical lead pellets known as shot. However, some shotgun cartridges are designed to fire a single projectile (slug) from a rifled-barrel shotgun, commonly used for beast destruction.

7.1.3.2 Live cartridges

Although fired cartridge cases and fired projectiles (Section 7.1.3.3) are the primary types of forensic firearms evidence recovered from crime scenes, the presence of unfired (live) cartridges is important to forensic firearms examiners. Live cartridges allow an examiner to determine exactly the type of ammunition that was used by the firer and can be used for corroborative intelligence and for test firing to assist in the identification of a specific weapon.

7.1.3.3 Fired cartridge cases and projectiles

Brief examination of fired cartridge cases can provide valuable intelligence to the forensic practitioners investigating the incident. Information can include the manufacturer and calibre of the likely ammunition used, and probable identification of the type of weapon, its manufacturer and model, using class characteristics transferred during the firing process (for example, the shape and dimensions of the firing pin impression). Knowledge of such initial intelligence can aid the forensic veterinarian in their examination of wounds (Section 7.2).

The fired ammunition component that is more commonly encountered by a forensic veterinarian is the fired projectile, which may or may not be located inside the injured species. Ideally, the presence of a forensic firearms examiner or ballistics expert would be very beneficial as they can assist with wound examination and interpretation and recover any firearms-related evidence; however, the overriding purpose of the veterinarian is to preserve life. As a minimum, an X-ray of the wound should be undertaken, as some initial visual analysis of the X-ray images can provide intelligence to the practitioner during their examination. The approximate dimension of the base of the projectile can indicate the calibre of the weapon, and the shape of projectile found may lead to the type of weapon that discharged it. Also, it is possible that the projectile may have fragmented inside the body; this could be due to the design of the ammunition component or because the projectile has struck dense material within the body; for example, bone. Retrieval of fired projectiles will be covered in Section 7.1.8.

Although beyond the scope of this chapter, submission of fired cartridge cases and projectiles to the laboratory for examination by a firearms examiner can further identify the specific weapon that was involved using microscopic examination of the individual characteristics engraved and impressed into the fired ammunition component. Individual characteristics are created by unique toolmarks generated on the surface of the weapon components during the component manufacturing process. The toolmarks are randomly created due to wear of the tool surface used to manufacture the component and these toolmarks are transferred to the component during the firing process. As they are random and unique, the individual characteristics can be used to identify a specific weapon component. Even if a firearm is not recovered, examination of multiple fired cases or projectiles can be used to link shooting incidents together and identify a single weapon used in one or more incidents, known as an inferred weapon.

7.1.4 Internal ballistics

Internal ballistics covers all aspects involving the ammunition and firearm from the moment the firing pin strikes the cartridge to the point at which the projectile exits the muzzle of the firearm. A range of scientific concepts underpin internal ballistics, which include combustion theory, Piobert's law of burning, the ideal gas law, laws of thermodynamics, conservation of energy and linear momentum, and Newton's laws of physics (Carlucci and Jacobson, 2008). This section will not explain these concepts in depth, but will introduce the various stages that comprise the ignition of typical modern cartridge-based ammunition.

7.1.4.1 Primer

When the base of the cartridge is struck by the firing pin, this creates an impression in the metal base known as the firing pin impression. The distortion to the base causes the case to strike a metal anvil positioned directly beneath, within the primer unit, thus creating a spark. The spark detonates the unstable, explosive inorganic primer producing a flame jet of approximately 2000°C (Heard, 2008).

The primer mixture comprises an igniter, an oxidizer and a fuel. The igniter is an explosive chemical compound such as lead styphenate or tetrazine (in lead-free ammunition). Barium nitrate is an oxidizer that aids flame production by providing oxygen during the reaction, and antimony sulphide is an example of the fuel needed to increase the temperature and length of the flame.

The flame is forced through one (boxer primer type) or two (berdan primer type) flash holes in the top of the primer unit, which provides sufficient thermal energy to ignite the propellant flakes housed in the main body of the cartridge case.

7.1.4.2 Propellant

Propellant is compressed grains of organic materials designed to burn at a controlled rate. In modern smokeless propellant (as opposed to black powder), nitrocellulose and/or nitroglycerine is the main component.

The shape and dimensions of the grains (ballistic size) and presence/absence of moderators, stabilizers and/or retardant chemicals within or coated on the grain surface(s) can control the burning rate of the propellant. As the grains combust, they produce a large volume of gas (primarily carbon dioxide and water vapour), which is sealed inside the cartridge case and chamber of the firearm. The temperature and pressure builds inside the cartridge, thereby increasing the burning rate of the propellant and resulting in an exponential rate of combustion. The initial rate of combustion is also determined by the ratio between propellant volume and case volume; a greater volume of unfilled space in the cartridge case will result in a slower combustion rate, as the gas has more space to fill before the pressure can start to rise. When the pressure is high enough in the cartridge it forces the projectile(s) free from the cartridge case; this is known as shot start (Farrar and Leeming, 1983).

7.1.4.3 Projectile

At shot start, the projectile(s) starts to travel down the barrel of the weapon and accelerates due to the work done by the high-pressure gas on the entire surface of the projectile base, which increases energy transferred to the projectile. Due to the increase in space behind the projectile, the pressure is still rising, but the propellant starts to burn at an increasingly slower rate. Peak pressure occurs approximately 0.5 ms after cartridge ignition and can be in excess of 300 MPa (Warlow, 2011).

If the barrel is rifled (see Section 7.1.5.2) then there will be some friction when the projectile engages with the slightly smaller dimension of the barrel bore created by lands of the barrel rifling. Some gas will escape in front of the projectile through the grooves of the rifling as these may be deeper than the maximum diameter of the projectile. If the barrel is smooth bore and multiple projectiles are fired from the cartridge, as with a shotgun, some gas may escape by passing between and around the shot inside the barrel.

At the time of peak pressure, the projectile may have only moved 2 cm. As the projectile accelerates and level of kinetic energy overcomes the initial frictional force, an increasing volume will be left behind the projectile and the rate of burning continues to reduce as the propellant flakes reduce in size and produce less gaseous products. Providing sufficient force is maintained as the propellant burns, the projectile(s) will pass down the barrel to the muzzle exit within 2 ms from the strike of the firing pin (Warlow, 2011).

The precise velocity of the projectile prior to exit will vary to some extent from the ammunition manufacturer's specifications, depending on the specifications of the model of firearm the ammunition is fired from. For example, for a given cartridge, the tighter the fit of the projectile within the barrel bore, the greater the level of friction initially acting against the forward motion of the projectile, and therefore the lower the muzzle velocity. If the barrel is longer, then frictional force may act for longer. There will also be some variability from cartridge to cartridge due to the tolerances during ammunition production and how the cartridge seats in the breech of the weapon.

7.1.4.4 Weapon

The detonation of the primer, combustion of the propellant and friction generated (typically for rifled barrels) between the barrel and the projectile will transfer thermal energy to the metallic firearm components, primarily the chamber and barrel. Lawton (2001) indicates barrel bore temperatures in the region of 1100°C, whereas Warlow (2011) suggests over 2200°C. Contact between firearm components and ammunition, together with these extreme temperatures, even over such a short period of time, will cause surface melting and enhanced wear of the weapon components.

When the propellant combusts, the pressure of the gases does not only act in the direction of the projectile base, but in all directions around the breech of the weapon. As a result, while the projectile remains inside the barrel, the pressure exerted forwards on the projectile is experienced backwards on the weapon, known as recoil. Typically, the greater the recoil velocity, the more uncomfortable the weapon is to fire. The production of high-pressure gas or recoil energy generated can be exploited in the weapon design and be utilized by the firing mechanism to eject fired cartridge cases after discharge and load new cartridges (auto-loading).

As the pressure acts in all directions, the muzzle of the weapon will also lift slightly above its point of aim, especially if the muzzle end of the weapon is unsupported.

Barrel lift will vary depending on the ammunition utilized and will ultimately affect shooting accuracy. This needs to be considered when sighting the weapon and firing in automatic modes.

7.1.4.5 Production of gunshot residue (GSR)

The inorganic primer and organic propellant will not completely burn during ignition of the cartridge. This generates a mixture of unburnt, partially burnt and still burning particles, referred to as gunshot residue (GSR) or firearms discharge residue. GSR will also contain some of the metallic particles produced from the wear of the firearm component surfaces, together with the ammunition materials removed by striated contact with the weapon components, such as the barrel. GSR particles predominantly exit the weapon once the projectile has left the muzzle, but some will escape before the projectile(s) exits and GSR will be carried by the escaping gaseous combustion products in gaps between the projectile(s) and bore surface. GSR will also exit from any opening within the firearm, such as the ejection port (semi-automatic weapon) or cylinder (revolver).

Partially burnt and still burning particles are important with respect to intermediate ballistics (Section 7.1.5), as well as being significant to forensic investigation. In the context of veterinary forensics, presence or absence of GSR can assist with determining firing distance between muzzle and the target, differentiating between initial entry and exit wounds and identification of the type of ammunition used (Heard, 2008; Brożek-Mucha, 2009; Dalby *et al.*, 2010; Haag and Haag, 2011; Warlow, 2011).

7.1.5 Intermediate ballistics

Intermediate ballistics is a transitional area covering the moment the projectile exits the barrel until the projectile is considered to be in free flight. Heard (2008) encompasses intermediate ballistics within the scope of wider external ballistics, whereas more specialized literature (Carlucci and Jacobson, 2008) classifies intermediate ballistics as an area in its own right. The time and distance that intermediate ballistics covers will vary, depending on the type of ammunition used and the ballistic properties of the projectile. This section will briefly discuss how the flow of gaseous combustion products and presence of muzzle attachments influence propellant particles and the motion of the projectile upon muzzle exit.

7.1.5.1 Propellant particles and gaseous combustion products

As previously discussed, high-pressure combustion products escape the muzzle in front of the projectile due to the high pressure release of gas after shot start, together with a column of air that is pushed forwards by the moving projectile. When these high-pressure gases exit the muzzle, a shock wave (precursor blast shock) is created just in front of the muzzle, travelling slightly above 340 m/s (speed of sound) and meets with the ‘normal’ atmosphere. This shock wave generates a sonic bang and radiates out in a spherical direction away from the muzzle.

Precursor bottle shock and the Mach disk also occurs around the muzzle as the precursor blast shock is trying to travel back inside the barrel, against the flow of gas (Carlucci and Jacobson, 2008). The bottle shock increases as the gas velocity increases; as gas velocity reduces the bottle shock will eventually shrink back inside the barrel.

When the projectile exits the muzzle, the gas seal is broken and a further release of highly pressurized gas is released into the atmosphere. A second high-pressure blast wave is formed, together with further bottle shock and Mach disk. This second blast wave is higher in pressure than the precursor blast wave and is initially non-spherical due to the projectile and flow of combustion gases. This blast wave accelerates the combustion products forwards, creating a turbulent column of gas. The column of gas initially overtakes the projectile, causing a shock wave around the base of the projectile (stern shock), which can accelerate the projectile and produce instability and yawing. The spherical blast shock is travelling faster and has more energy than the precursor blast shock and catches up with it; shock waves lose energy and velocity as they increase in size and the gas molecules dissipate.

Within the gaseous combustion products, still burning propellant particles are also present. These particles exit from the barrel in front of the projectile, but are predominantly built up behind the projectile. As these particles pass through high-pressure shock waves, their temperature and burning rate increases producing visible light (incandescent radiation), known as muzzle flash. Preflash can occur before the projectile exits the muzzle, but primary muzzle flash occurs at the muzzle of the firearm after projectile exit. Intermediate muzzle flash can occur further from the muzzle. As the gases in the bottle shock expand rapidly they cool down and a faint muzzle glow can be seen moving away from the muzzle.

Once all the combustion products have been released from the barrel, there is a void in the barrel bore. As the blast shock radiates out in all directions, the blast wave can then recede down the empty barrel along with some of the combustion products. If a target is in close proximity to the muzzle upon discharge, it is this vacuum effect which sucks the target material back inside the barrel, which can therefore be of forensic significance when interpreting the shooting incident.

7.1.5.2 Projectile

Upon muzzle exit, the projectile is in a turbulent atmosphere and is therefore not fully stabilized. This can have varying degrees of impact on the projectile, depending on its shape. For example, cannonballs and shot are typically spherical and therefore turbulence will affect the object similarly in all directions. With most other types of projectile, however, they are designed to be aerodynamic and stable during free flight and may have characteristic features (such as fins) on the surface to ensure that the projectile arrives at the target nose first.

Turbulence created by the combustion products initially destabilizes these projectiles, causing the projectile to yaw slightly (1.5° for a 0.303-in. rifle bullet (Heard, 2008)), i.e. the nose to rise or fall above or below the projectile's line of flight base, which increases the surface area presented at the projectile nose. Such increase in surface area increases the air resistance around the projectile, reducing projectile velocity and, without a rotational force about the centre of mass, this would cause the bullet to tumble. Tumbling would ultimately reduce projectile velocity, energy, distance (range), accuracy, precision of fire, but increase damage/wound potential due to an increased surface area upon contact with the target.

To counteract destabilization, the rifling inside the barrel consists of spiral lands and grooves. The higher-profile lands on either side of the grooves in the barrel bore are smaller in diameter compared to the maximum diameter of the projectile and therefore engrave into the surface of the projectile, gripping the projectile and bringing about rotation as the projectile travels down the barrel. Upon muzzle exit, the projectile will be rotating at a pre-defined rate. This rotation helps to re-stabilize the projectile as it travels through the turbulent gas due to gyroscopic nutation and thus, the rate of rifling twist down the barrel is important for optimum stabilization of the projectile.

Depending on the muzzle velocity of the projectile, the projectile will either not reach the blast wave (subsonic projectile), or overtake the blast shock (supersonic projectile) and generate a shock wave and audible sonic bang from the nose of the projectile. With supersonic projectiles, a further shock wave and sonic bang will be created when the base of the projectile subsequently passes through the blast shock.

7.1.5.3 Muzzle attachments

Heard (2008) indicates there are six types of muzzle attachment for pistols, revolvers, rifles and shotguns:

1. Sound suppressors.
2. Recoil reducers (compensators).
3. Flash hiders.
4. Muzzle counter weights (to reduce muzzle lift).
5. Grenade dischargers.
6. Recoil boosters.

Only the first three will be discussed here, as these have a direct influence on intermediate ballistics.

Sound suppressors are predominantly designed to reduce noise generated from an expanding gas pressure wave by 18–32 dB (Heard, 2008). They also act to reduce flash and recoil to some extent. Such attachments lower the energy of the gas by allowing the gases to expand within a closed container, by increasing the volume the gas flows into or by making the gas do mechanical work (moving a rotor, for example), or by reducing the temperature through absorption. Those suppressors that are built into the barrel can also reduce the muzzle velocity of the projectile to less than the speed of sound, thereby preventing the supersonic boom of firing by bleeding off some gas near the muzzle of the weapon.

Recoil reducers (or muzzle brakes) are designed to direct the muzzle gas sideways rather than in a primary forwards motion. Gas deflection is obtained by placing one or more sets of symmetrical ports along the sides of the muzzle attachment for gases to escape.

Modern flash hiders are usually the simplest type of muzzle attachment. These devices are primarily designed to reduce intermediate muzzle flash by dispersing the muzzle gas and breaking up the barrel shock and Mach disk. They are usually cone-shaped, a tube with odd-numbered slots, or a bar style (Farrar and Leeming, 1983; Carlucci and Jacobson, 2008).

7.1.6 External ballistics

External ballistics covers the period of flight from the point at which the projectile is stable and behaving within ‘normal’ atmospheric conditions until the moment it comes into contact with an object. Like internal ballistics, this aspect is very complex and involves extensive mathematical computation to determine a projectile’s flight path. This section considers basic concepts that critically underpin this area of applied physics.

7.1.6.1 Muzzle velocity and kinetic energy

During internal ballistics, approximately 30% of the energy created is actually transferred to the projectile(s) (Warlow, 2011), predominantly in the form of kinetic energy, resulting in acceleration of the projectile(s) to a known velocity. Following muzzle exit and a very short distance past the muzzle, the projectile reaches a maximum velocity, referred to as muzzle velocity. Muzzle velocity is pre-determined by the ammunition manufacturer; however, as previously explained, fired projectiles may not reach the technical specification of muzzle velocity quoted by the ammunition manufacturer.

Kinetic energy and muzzle velocity are two of three linked factors; the third component that affects muzzle velocity and the kinetic energy is the projectile mass. Kinetic energy is calculated by squaring the velocity and then multiplying this by half the mass of the projectile. As the mass of the projectile increases, a greater amount of work, force and energy is required to move the projectile the same amount. Therefore, for two projectiles of different masses to have the same muzzle velocity, more kinetic energy (and therefore a higher gas pressure) is required to fire the heavier projectile. A projectile with higher mass will ultimately enhance its ‘carrying power’ (Heard, 2008).

When considering terminal ballistics later on, the kinetic energy of the projectile is of greater importance than the velocity of the projectile, as kinetic energy takes into account both projectile mass and velocity. It is also the ability of the projectile design to transfer energy to the other object that impacts on the resulting damage to the object.

As soon as the projectile exits the muzzle, the energy and force acting on the projectile is in the forwards (horizontal) direction away from the muzzle, therefore the velocity vector has a positive value. Initially this will be the dominant direction of force acting on the projectile. However, unless the projectile is fired into a vacuum, there will always be forces acting against the projectile in the opposite direction limiting the forwards progression, reducing the kinetic energy and therefore the velocity of the projectile over time. These opposing forces are from the interaction with molecules within the atmosphere; the phenomenon is known as air resistance (drag). The forward movement of the projectile compresses the air molecules in front of it causing areas of higher pressure which act in all directions around the front of the projectile. Minimizing the cross-sectional area of the projectile and making the projectile less angular will reduce air resistance. The air molecules then flow around the projectile, a small amount of surface (skin) friction is created between the air molecules and the sides of the projectile, further reducing the kinetic energy and velocity of the projectile.

When the air molecules have passed over the sides of the projectile, they have to fill in the space left by the base of the projectile. This again causes high-pressure regions at the back edges of the projectile and leaves a turbulent wake of gas behind the projectile. The shape of the nose and base of the projectile are therefore critical to limiting the effect of air resistance on the kinetic energy and velocity of the projectile. A more aerodynamically shaped projectile will exhibit a slower decline in velocity and kinetic energy due to air resistance. Aerodynamically shaped projectiles will display a long, sharp and low-angled nose (spitzer) to reduce the cross-sectional surface area initially presented to the air and may even have a slightly angled base (boat-tail) to improve the flow of air particles and reduce turbulence from air molecules behind the projectile. The term ballistic coefficient is used to calculate the decline in projectile velocity due to the air, and takes into account projectile mass and diameter (Carlucci and Jacobson, 2008). Typically, the higher the ballistic coefficient, the better a projectile retains its velocity over time. Using data provided by Forker (2010), Table 7.1.2 and Fig. 7.1.2 illustrate how the projectile energy changes for some common cartridges.

7.1.6.2 Trajectory

Air resistance is not the only force acting on the projectile. Acceleration due to gravitational pull from the Earth is constantly acting downwards in the vertical direction on the unsupported object at 9.81 ms^{-2} (Haag and Haag, 2011). As a result, the natural flight path or trajectory will always ultimately curve downwards towards the ground (bullet drop), unless the trajectory is prematurely interrupted by an object.

Table 7.1.2. Examples of various cartridges.

Firearm Type	Cartridge	Manufacturer	Projectile Type	Bullet Weight (g)	G1 Ballistic Coefficient	Muzzle Velocity (fps)	Muzzle Velocity (m/s)
Revolver	0.357 Magnum	Sellier and Bellot	FMJ	158	0.154	1263	385
Pistol	0.45 ACP	American Eagle (Federal)	FMJ	230	0.178	890	271
	9×19 mm	Sellier and Bellot	FMJ	115	0.102	1280	390
Rifle	0.22 Hornet	Sellier and Bellot	FMJ	45	0.102	2346	715
	0.223 Remington	American Eagle (Federal)	FMJ Boat-tail	55	0.270	3240	988
	0.303 British	Sellier and Bellot	FMJ	180	0.564	2438	743
	0.458 Winchester Magnum	Hornady	DGX	500	0.295	2260	689
	7.62 mm NATO	American Eagle (Federal)	FMJ Boat-tail	150	0.409	2820	860

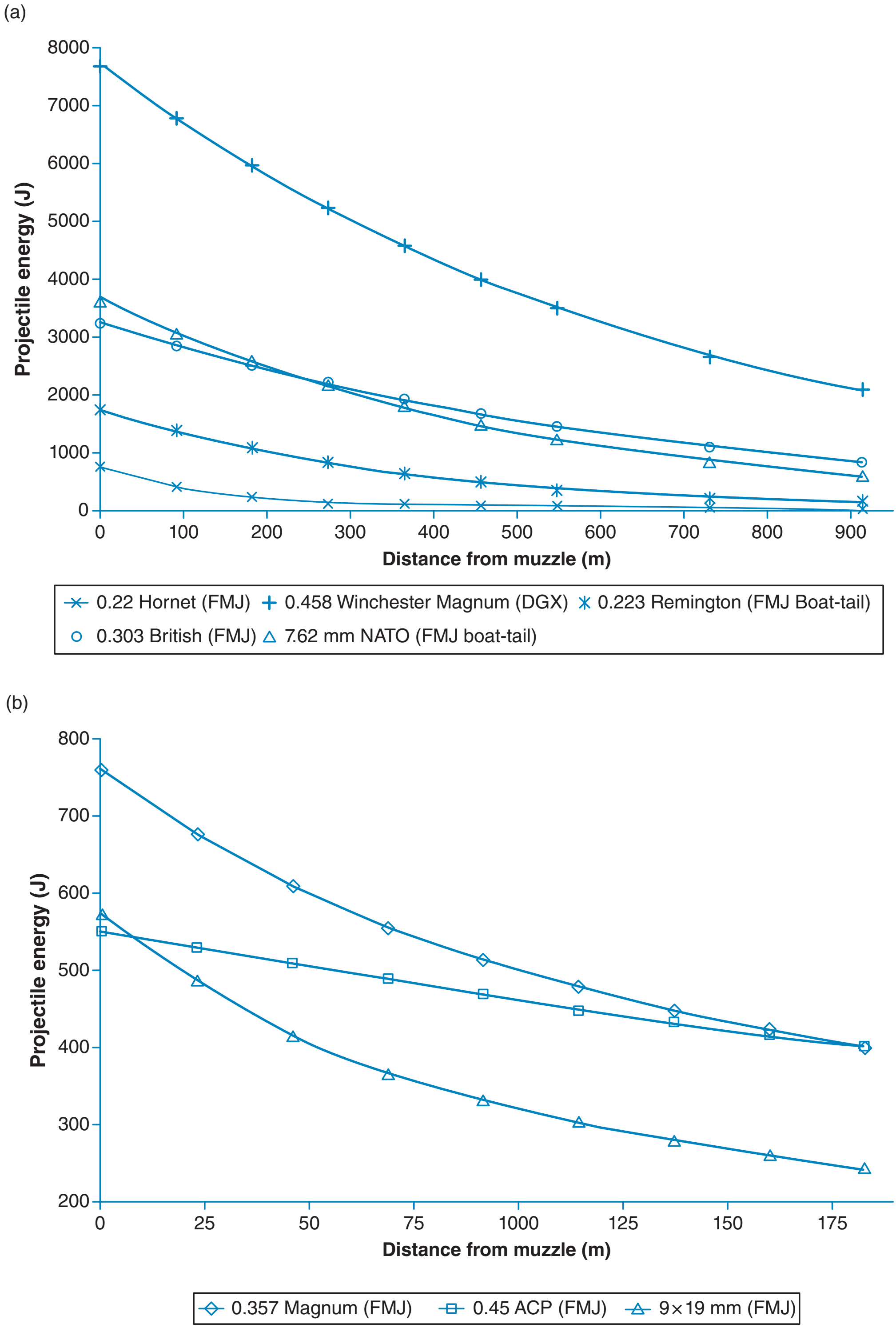

Fig. 7.1.2. Projectile energy changes for some common cartridges.

The initial projectile trajectory will be affected by the muzzle firing angle (angle of inclination). However, it is typical for the projectile not to exit the muzzle aligned with the bore so it will experience vertical and lateral jump (Carlucci and Jacobson, 2008) caused by air resistance. Considering only the effect of vertical gravitation force on a projectile fired in a vacuum at 45°, for example, the trajectory would be a symmetrical parabolic curve about a peak height.

In atmospheric conditions, this parabolic curve is no longer symmetrical due to the effect of air resistance (wave drag, base drag and skin friction). The forces counteracting the forward motion of the projectile will cause the projectile not to reach as high vertical distance or as long horizontal distance (range). The velocity of the projectile will reduce over the time of flight at an exponential rate; therefore, the faster the muzzle velocity of the projectile, the greater the velocity lost per unit of time.

Many firearms are discharged at relatively low-angle (flat) trajectories over relatively short range; however, when the target is positioned at a significant range or the projectile needs to travel over obstacles in the line of sight, higher angles of trajectory are employed, exploiting the curved trajectory.

7.1.6.3 Range

Maximum effective range of real projectile trajectories can be difficult to calculate. Range is affected by the muzzle velocity, the mass, shape and cross-sectional area of the projectile. Other effects include altitude, barometric pressure, crosswind, humidity and temperature. However, to consider the effects of all these variables is outside the scope of this chapter.

As velocity is calculated by dividing distance by time, the greater the velocity of the projectile, the further the projectile will travel in a set period of time. To maximize range, the aerodynamic shape and geometry of the projectile are critical depending on projectile muzzle velocity (subsonic or supersonic). Subsonic projectiles are most influenced by base drag, whereas supersonic projectiles are most influenced by wave drag, and therefore the nose of supersonic projectiles needs to be designed to minimize drag.

Angle of inclination has a significant role in the maximum potential range of fire for a projectile. For a specific projectile fired in a vacuum on Earth, the time spent in free flight for the same ammunition will be identical, but the maximum range will be obtained when there is as much forwards motion as vertical motion. Maximum theoretical range will therefore occur at 45° inclination due to the trajectory's symmetrical shape; 30° and 60° firing angles will result in identical, but reduced, range of fire compared to 45°.

Considering the impact of firing angle alone in atmospheric conditions, maximum range will typically be generated when fired between 27° and 30° (Carlucci and Jacobson, 2008), although Haag and Haag (2011) indicates 30° to 35° for handgun cartridges. The accent of the projectile to peak height will be slightly lower and of less distance compared to in the vacuum, but the biggest effect to range occurs during projectile descent to ground. Pistol and revolver bullets, when fired at their optimum departure angle can reach a maximum range of 1000–2000 m, whereas rifle bullets can reach between 3000 m and 4000 m (Haag and Haag, 2011).

Shot need to be considered separately. Shot are spherical, symmetrical and do not require stabilization by rotational force. Spheres are less aerodynamic, and these projectiles are not designed to be fired over long distances. Their maximum range in air has been demonstrated to be 1–3% of the range achieved if fired in a vacuum (Chugh, 1982) compared to approximately 20% for bullets. As there are multiple projectiles, shot spread out over range and can be used more effectively for distance determination (Çakir *et al.*, 2003; Haag and Haag, 2011).

7.1.6.4 Accuracy and precision

The accuracy (closeness to the intended point of impact) and precision (spread around the intended point of impact) of the projectile will be affected by the firer, weapon and atmospheric conditions, including wind speed and direction, the extent of which is outside the scope of this chapter; however, some examples are considered.

The weapon type is important to consider. Handguns are typically designed for close combat and therefore less accurate and precise over distance than rifles. Generally, this is due to the shorter barrel and less aerodynamic projectiles. By design, shotguns firing a number of shot are primarily used for hunting and therefore accuracy and precision are less critical as there are multiple shot that spread out as range of fire increases, and therefore the shot are more likely to penetrate and strike the animal.

Firing a brand new weapon from a fixed firing position should provide excellent accuracy and precision. Over time, as weapon components such as the barrel suffer from wear, the tolerance to generate a stable projectile during flight increases and this has a negative effect on accuracy and precision. Incorrect support, handling and aim of the weapon during firing (Goonetilleke *et al.*, 2009) will reduce accuracy and lower precision due to recoil forces, whereas reducing the trigger pull force required to action the trigger mechanism and discharge a round can increase precision and accuracy.

7.1.7 Terminal ballistics

Energy and design of the projectile as well as the density, material properties and surface roughness will affect what happens to the projectile when it hits a target surface. Target materials that are less dense and more malleable than the projectile materials are more likely to deform, be penetrated to some extent and absorb more energy from the projectile, compared to those that are denser and have greater hardness. Yielding surfaces that deform upon impact produce greater angles of projectile ricochet than unyielding surfaces (Haag and Haag, 2011).

The design of the projectile will have an effect on the potential for ricochet. Some projectiles (e.g. soft-point or hollow-point bullets) are designed to mushroom at the nose to increase surface area and increase the transfer of energy from the projectile to the target. The consequence is a greater damage/wounding potential. FMJ projectiles, however, are not designed to deform on impact and therefore do not transfer as much energy into the target, ultimately reducing the damage/wound potential and increasing the depth of penetration into the target.

The angle at which the projectile hits the target also affects whether the projectile is more likely to penetrate into the target or ricochet, i.e. deflect off the target surface. For every combination of specific projectile design and target surface, there will be a critical angle that determines whether the projectile penetrates or has the potential to ricochet. Generally, the critical angle will be relatively low (oblique) and the projectile typically ricochets off at a comparably lower angle (Haag and Haag, 2011).

The effect of ricochet and tumbling will affect the size and shape of penetrating wounds (Section 7.2). Tumbling or instability in a projectile will cause it to yaw. If the projectile hits an animal in a state of yaw rather than perpendicular and nose first, the surface area where impact occurs is increased and therefore the size of the entry wound may be increased. Such impact angle can also transfer energy into the animal/target more effectively. However, if the projectile is designed to transfer energy effectively (for example, a hollow-point or soft-point) then the energy transfer may be less effective as the nose will not be able to perform as designed.

7.1.8 Retrieval of fired ammunition components

7.1.8.1 Cartridges and fired cartridge cases

If you are called to a crime scene of a suspected shooting, the forensic veterinarian should be aware of the potential for finding live ammunition as well as fired cartridge case evidence. Depending on the nature of the scene and the location of the incident geographically, there will be a variety of policies governing who recovers this physical evidence. The purpose of this section is to remind the practitioner that such evidence has forensic value in inferring the calibre and type of firearm likely to have discharged the cartridge, the number of weapons involved, and has the potential to link crimes utilizing discharge of the same weapon in various cases; and microscopic examination of fired cartridge case evidence can uniquely identify the firearm that discharged it, if a weapon is ultimately recovered.

If unfired ammunition is discovered, the cartridges need to be recovered using good practice to minimize contamination, such as wearing gloves, and should be packaged separately to any weapon recovered to minimize risk and prevent accidental firing. Cartridges should be packaged in paper bags, cardboard boxes or plastic containers (Tilstone *et al.*, 2013) lined with non-abrasive material (not cotton wool) to prevent them rolling around during transportation.

If fired cartridge cases, shotgun wadding (typically made of fibre or plastic) and/or projectiles are observed in the scene surroundings they should be recovered using *plastic* forceps or tweezers, to prevent damage to the evidence surface (Bruce-Chwatt, 2010). Handling items with metal tweezers of a harder material than the evidence may cause permanent toolmarks on the evidence surface, that could damage or impede forensic examination and interpretation subsequently undertaken by firearms examiners. Fired cartridge cases, like the cartridges themselves, should be packaged as they are recovered from the scene in paper bags, cardboard boxes or plastic containers lined with polythene/non-abrasive material (not cotton wool), with the latter preferably used for fired projectiles and wadding.

7.1.8.2 Fired projectiles and shotgun wadding

Fired projectiles, such as bullets, pellets (air weapons), slugs or shot (shotgun) may be present in the animal. Even legal unlicensed air weapons can penetrate animal skin, but research has shown that the type of animal (Wightman *et al.*, 2013) and the thickness and material properties of their skin will influence the ability for the pellet to penetrate, together with the energy and shape of the projectile.

As previously stated, any fired projectiles recovered should be handled with plastic tweezers or forceps to prevent damage to the forensic characteristics. Upon recovery of the projectile, this should be washed with sterile water to remove biological hazards (different protocols are required for projectile retrieval from humans) and air-dried before packaging, to prevent any corrosion of the projectile material surface. Packaging for fired projectiles is ideally in polythene and plastic containers, i.e. not containing cotton wool.

Wadding components within shotgun cartridges are ejected from the cartridge along with the single slug or multiple shot. This can travel over 30 m from the muzzle of the weapon (Bonfanti and De Kinder, 2013) and, therefore, finding wadding inside a wound tract or permanent cavity can imply that the weapon has been discharged at close range to the target. Recovery and packaging of shotgun wadding should be as described above for fired projectiles.

7.1.8.3 Gunshot residue (GSR)

GSR can be sampled with commercially available GSR collection kits by swabbing around the area of the wound entry. GSR may be differentiated from other metallic residues (Romolo and Margot, 2001; Dalby *et al.*, 2010; Grima *et al.*, 2012) and can sometimes be uniquely identified to a type of ammunition (Brozek-Mucha and Jankowicz, 2001); for example, if the composition of the primer is very distinctive. GSR can be indicative of close range of fire (Ditrich, 2012), as can the presence of stippling, powder tattooing on the skin and burning of hair from burning propellant flakes and hot gases released from the muzzle of the firearm. However, if an air weapon was utilized, such characteristics will not be present around an entry wound, even at close proximity, as there is no combustion of propellant used to propel the pellet out of the weapon.

7.1.9 Conclusion

This section aimed to introduce some of the key scientific principles underpinning shooting incidents that may influence observed wounding in animals. Variations in the type of firearm and ammunition (internal ballistics) used in the shooting as well as environmental conditions and shooting distances (external ballistics), location of impact, composition of the target material and design of the projectile upon impact (terminal ballistics), for example, may all cause variations in the expected severity of damage and lethality. By understanding how these factors may affect wounding, potential forensic veterinarians may have an increased capacity to interpret the manner in which injuries have been sustained and provide further information to the forensic investigative process.

The essential steps in the forensic examination and investigation of a shot animal were identified, clearly highlighting the requirement for a logical and methodical approach supported by extensive documentation. The approach for animals should be similar to that conducted on humans and all wound ballistics research may be relevant for consideration in application to animal practice. It is vital for external observations to be completed before invasive internal examination commences, and modern non-invasive imaging technologies, including computer tomography (CT) and ultrasound, should be employed at the earliest opportunity. Use of such technologies facilitates the formation of the forensic examination strategy by providing visualization of bullet-wound channels, projectiles or projectile fragments, and the presence of fractures and other damage in the animal prior to invasive action.

Firearms evidence collated from both the crime scene and the injured animal can provide vital information and intelligence to those investigating both domestic animal and wildlife crimes. The form and extent of firearms evidence that may be located at a crime scene will also vary, depending on the firearm, ammunition and ballistic variables. Correct handling and recovery of such evidence is important for any further analysis requested to be probative in the case. Demonstration of the breadth of knowledge required to investigate shooting incidents may highlight the need for forensic veterinarians to get in contact with subject experts to provide support prior to and during forensic examinations and any subsequent investigation. By building a strong prosecution case, including corroborative evidence from firearms examiners, investigators are more likely to be able to link crime series and identify those involved in the crimes, to ultimately increase the probability of prosecution and conviction in forensic cases.

References

AFTE Training and Standardization Committee (ed.) (2007) *Glossary of Association of Firearms and Tool Mark Examiner*, 5th edn. AFTE, Montreal, Canada. Available on CD-ROM.

Berman, G. (2012) *Firearm Crime Statistics.* SN/SG/1940. House of Commons, London, UK.

Bolton-King, R.S. (2012) Classification of barrel rifling transitions for the identification of firearms. PhD thesis. Nottingham Trent University, Nottingham, UK.

Bonfanti, M.S. and De Kinder, J. (2013) Shotgun ammunition on a target. In: Siegel, J.A., Saukko, P.J. and Houck, M.M. (eds) *Encyclopedia of Forensic Sciences*. Academic Press, Waltham, Massachusetts, USA, pp. 48–53.

Brożek-Mucha, Z. (2009) Distribution and properties of gunshot residue originating from a Luger 9 mm ammunition in the vicinity of the shooting gun. *Forensic Science International* 183(1–3), 33–44.

Brozek-Mucha, Z. and Jankowicz, A. (2001) Evaluation of the possibility of differentiation between various types of ammunition by means of GSR examination with SEM–EDX method. *Forensic Science International* 123(1), 39–47.

Bruce-Chwatt, R.M. (2010) Air gun wounding and current UK laws controlling air weapons. *Journal of Forensic and Legal Medicine* 17(3), 123–126.

Çakir, I., Çetin, G., Uner, H.B. and Albek, E. (2003) Shot range estimation based on pellet distribution in shots with a pump-action shotgun. *Forensic Science International* 132(3), 211–215.

Carlucci, D.E. and Jacobson, S.S. (2008) *Ballistics: Theory and Design of Guns and Ammunition*. CRC Press, Boca Raton, Florida, USA.

Chugh, O.P. (1982) Maximum range of pellets fired from a shotgun. *Forensic Science International* 19(3), 223–230.

Dalby, O., Butler, D. and Birkett, J.W. (2010) Analysis of gunshot residue and associated materials – a review. *Journal of Forensic Sciences* 55(4), 924–943.

Demirci, S., Dogan, K.H. and Koc, S. (2011) Fatal injury by an unmodified blank pistol: a case report and review of the literature. *Journal of Forensic and Legal Medicine* 18(6), 237–241.

Ditrich, H. (2012) Distribution of gunshot residues – the influence of weapon type. *Forensic Science International* 220(1–3), 85–90.

Farrar, C.L. and Leeming, D.W. (1983) *Military Ballistics: A Basic Manual*. Brassey's, London, UK.

Forker, R. (2010) *Ammo and Ballistics 4*, 4th edn. Safari Press, Huntington Beach, California, USA.

Goonetilleke, R.S., Hoffmann, E.R. and Lau, W.C. (2009) Pistol shooting accuracy as dependent on experience, eyes being opened and available viewing time. *Applied Ergonomics* 40(3), 500–508.

Grima, M., Butler, M., Hanson, R. and Mohameden, A.O. (2012) Firework displays as sources of particles similar to gunshot residue. *Science and Justice* 52(1), 49–57.

Haag, M.G. and Haag, L.C. (2011) *Shooting Incident Reconstruction*, 2nd edn. Academic Press, San Diego, California, USA.

Heard, B.J. (2008) *Handbook of Firearms and Ballistics: Examining and Interpreting Forensic Evidence*, 2nd edn. John Wiley, Chichester, UK.

Home Office (2014) *Guide on Firearms Licensing Law*. Home Office, London, UK.

Jones, R.D. and Ness, L.S. (eds) (2009) *Jane's Infantry Weapons 2009–2010,* 35th edn. Jane's Information Group, Surrey, UK.

Lawton, B. (2001) Thermo-chemical erosion in gun barrels. *Wear* 251(1–12), 827–838.

Northern Ireland Office (2005) *Guidance on Northern Ireland Firearms Controls*. Northern Ireland Office, Stormont, Belfast, Northern Ireland, UK.

Oxford University Press (2014) *Oxford Dictionaries: British and World*. Available online at: http://www.oxforddictionaries.com (accessed 10 August 2014).

Romolo, F.S. and Margot, P. (2001) Identification of gunshot residue: a critical review. *Forensic Science International* 119(2), 195–211.

Smith, K., Osborne, S., Ivy, L. and Britton, A. (eds) (2012) *Homicides, Firearm Offences and Intimate Violence 2010/11: Supplementary Volume 2 to Crime in England and Wales 2010/11*. Home Office Statistical Bulletin, 02/12 edn. Home Office: London. Available online at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/116483/hosb0212.pdf (accessed 28 August 2014).

Squires, P. (2014) *Gun Crime in Global Contexts*. Routledge, Abingdon, Oxfordshire, UK.

Tilstone, W.J., Hastrup, M.L. and Hald, C. (2013) *Fisher's Techniques of Crime Scene Investigation: First International Edition*. CRC Press, Boca Raton, Florida, USA.

UK Parliament (1988) *Firearms (Amendment) Act 1988*. Available online at: http://www.opsi.gov.uk/acts/acts1988/pdf/ukpga_19880045_en.pdf (accessed 10 August 2014).

Warlow, T. (2011) *Firearms, the Law, and Forensic Ballistics* (International Forensic Science and Investigation), 3rd edn. CRC Press, Boca Raton, USA.

Wightman, G., Cochrane, R., Gray, R.A. and Linton, M. (2013) A contribution to the discussion on the safety of air weapons. *Science and Justice* 53(3), 343–349.

7.2 Wound Ballistics

JOHAN SCHULZE

7.2.1 Introduction

A standard rifle projectile like the 308 Winchester travels with a velocity of about 800 m/s (2625 fps). It takes the projectile less than 0.5 ms to penetrate the skin and to create a wound channel approximately 30 cm (1 ft) long (Braathen *et al.*, 2006). The challenge for the medical investigator is to understand the interaction between projectile and body that takes place within this time frame and to estimate how the body responds to this. He then has to relate this knowledge to his investigation, and if possible formulate an opinion appropriate to answer the demands of the legal system. Interpretations of wound patterns which may be appropriate to human cases may not be directly transferable to animal forensic investigation and should be undertaken with caution.

I will first discuss some basic wound ballistics by looking at the interaction between a body and a penetrating projectile. Next, some specifics not discussed in the first part are highlighted. Finally, essential steps in examination of an animal which has been shot will be outlined. Readers with a special interest in wound ballistics are referred to literature including Fackler (1987), Di Maio (1999), Brinkmann and Madea (2004), Munro and Munro (2008) and Kneubuehl *et al.* (2011).

7.2.2 Basics of wound ballistics

When investigating injuries caused by a projectile, the most important topic is the wound channel caused by the passage of the projectile through the body. No two wound channels are alike. Innumerable modifying factors make it impossible to accurately predict the course or form of a particular wound channel. Nevertheless, some important physical mechanisms are well established and knowledge of them is crucial when working with such injuries. The following describes a wound channel caused by a *non-deforming, non-fragmenting rifle bullet*. Other types of projectiles and weapons will cause other effects, and some of these are discussed later in the chapter.

A bullet entering a dense medium, like a body (or ballistic gelatine), transfers energy to the medium into which it penetrates. Wounding mechanisms of stretching, compression and shearing are initiated. Particles directly struck by, or close to, the projectile receive a radial accelerative force causing their temporary displacement perpendicular to the axis along which the projectile travels. The effect of this radial dislocation can be compared with a hard and radiating punch originating from the wound channel. The centrifugal movement of the medium lasts until the transmitted energy is spent or is absorbed by elastic tissues (or gel). At this state, about 2–4 ms after the hit, the moving projectile has not only created a wound channel approximately the diameter of its calibre, but also an additional larger cavity. This cavity, known as the *temporary wound channel*, collapses immediately as the elasticity of the tissue allows the particles to return towards their original position, hereby releasing the stored energy. Depending on the tissue or medium involved, the pulsation away from and towards the permanent wound channel continues until all transferred energy has been translated into friction and thermal energy. Naturally, this forceful radial pulsation causes anatomical and physiological damage in the living tissue.

Anatomical damage is mainly crushing and tearing. Some tissue close to the passing projectile may also be destroyed by the heavy centrifugal acceleration described above. This central core of the wound channel, originated by the destruction of tissue by the projectile, is called the *permanent wound channel*. The permanent wound channel is encircled by the now relocated but previously compressed tissue that had circumscribed the temporary wound channel. In contrast to the debris related to that of the permanent wound channel, this latter tissue zone has (at least for the meanwhile) maintained viability, despite having been through forced radial pulsation.

Though viability may be maintained, it is obvious that tissue close to the permanent wound channel, having been stretched and compressed considerably more forcibly, is likely to show more severe damage than tissue that is more distant. An area surrounding the permanent wound channel, named the *extravasation zone* (Fig. 7.2.1), is characterized by haemorrhage from lacerated capillaries. The haemorrhages are caused more by the stretching of blood vessels, to which they are very vulnerable, than by their being torn (Kneubuehl *et al.*, 2011). Bones are far less elastic. The size of a penetration through a flat bone, like a scapula, can be a very close approximation of the calibre of the projectile (Karger, 2004).

The overall form of the wound channel is far from homogenous. Its shape is a direct result of the amount of energy transferred from the projectile on its path through the tissue. The more energy that is transmitted, the harder is the impact and consequently the greater the dimensions of the permanent and temporary wound channels. The amount of energy transmitted per unit distance (E_{tr}) is proportional to the amount of energy the projectile has stored (E) and inversely proportional to its sectional density (m/A). The sectional density is defined as the ratio of the mass of the bullet (m) to the cross-sectional area of contact between bullet and medium (A).

$$E_{tr} = E/(m/A)$$

A bullet travelling perpendicularly to the plane of contact (*tip-first* position) has a small cross-sectional area. Hence the amount of energy transferred is low compared to the same bullet having rotated and thus presenting a larger cross-sectional area.

In Fig. 7.2.1 below, the longitudinal section in the lower part of the figure covers the total length of the wound channel; the two cross-sections in the upper part illustrate the profile of the wound channel at the levels of the narrow channel (left) and temporary cavity (right).

It is difficult to appreciate a detailed impression of the extent of a wound channel in

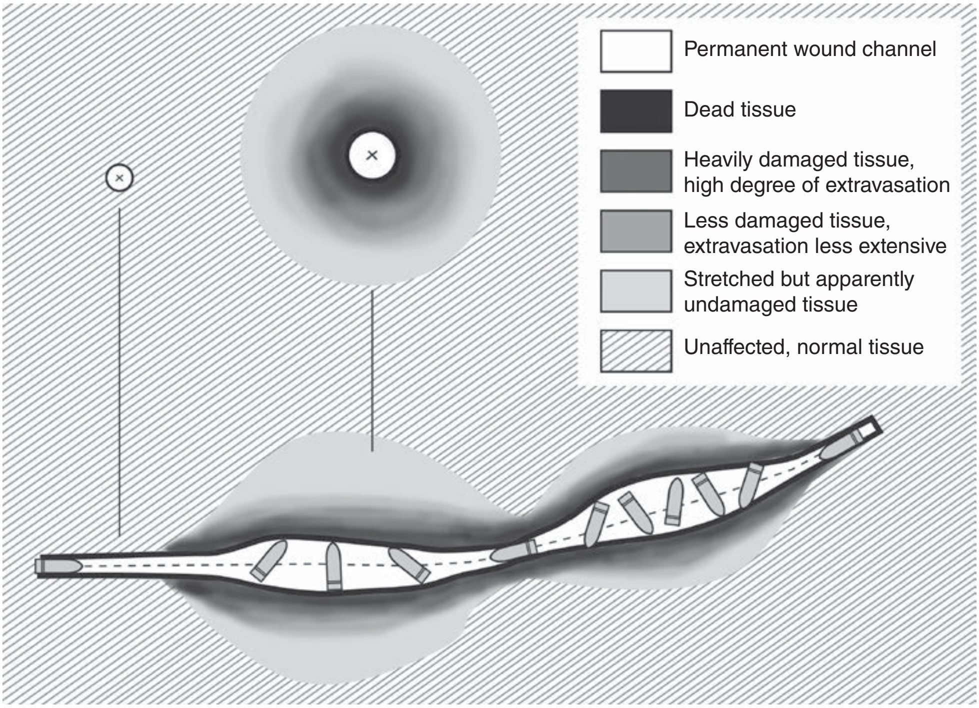

Fig. 7.2.1. Idealized schematic diagram of a wound channel created by the movement of a non-deforming rifle bullet through tissue (based on Kneubuehl *et al.* (2011) and Karger (2004)).

a body. Fortunately the physical processes involved have been visualized by experiments, mainly through the study of wound channels in simulants for natural bodies such as ballistic gelatine and soap (Nicholas and Welsch, 2004).

Long and slender rifle bullets striking the surface perpendicularly can stabilize themselves in the tip-first position. The exposure of a small cross-sectional area leads to both permanent and temporary wound channels initially being narrow, termed *narrow wound channel*. While slowing down, however, the projectile becomes increasingly unstable and starts to tumble as it proceeds. At this point, the narrow wound channel ends and the second part of the wound channel begins (Fig. 7.2.1). The tumbling motion causes presentation of parts of the bullet's side to the medium. The cross-sectional area of contact increases momentarily while the mass of the projectile, due to the law of inertia, initially ensures the maintenance of its velocity. The dramatic increase of transferred energy is accordingly reflected in the dimensions of the wound channel, which consequently expands, often considerably.

Having lost stability along the longitudinal axis, the projectile rotates around its transversal axis. In general the rotation will first turn the projectile into a position approximately 90° to its direction of movement. Because of inertia, however, the projectile may continue to rotate to 180°, or even up to 270°, out of line. At the same time, the bullet is decelerated far more markedly than in the narrow wound channel.

Clearly, more extensive injuries are to be expected from the tumbling of a long, fast-travelling rifle projectile than from a shorter and slower handgun bullet.

Even in a homogenous medium, the axis of the wound channel is not necessarily straight. When not in tip-first position, the cross-sectional area of the bullet is asymmetric. The sum of the withstanding forces affecting the projectile is not solely directed towards the opposite direction to that of the motion of the bullet. Hence the bullet receives an additional force vectored perpendicularly to its direction of travel. This force can be strong enough to change considerably the previous direction of travel of the projectile. This effect may be increased considerably with passage through heterogeneous tissues.

During the last phase of the bullet's journey, particularly the last part of the wound channel, the projectile stabilizes itself, taking a position with its longitudinal axis perpendicular to its direction of movement. In this phase, the projectile has already transferred much of its embedded energy. The kinetic energy transformed in rotation is more and more matched, and finally zeroed, by the resisting medium. The projectile moves through the medium, oscillating round its centre of mass. If the off-centred positioned tip swings faster forward, it meets a higher resistance than the opposite base, and vice versa. Thus a self-adjusting mechanism stabilizes the projectile until it comes to rest, ending the wound channel.

Projectiles may be found with their tail towards their direction of travel. They may also be found slightly withdrawn from the end of the wound channel. This phenomenon is due to residual negative pressure in the temporary wound channel that pulls the projectile slightly backwards once its forward movement has ceased.

This description of the formation and structure of ballistic wound channels is necessarily simplified, with the discussion focusing on a rifle bullet that does not deform, break up or fragment. There are many modifying variables that can alter this picture, but already certain principles are apparent. Thus, when considering missile wound injuries, we may be able to form conclusions or consider different scenarios.

- *The capacity of a bullet to cause injuries does not primarily depend on its energy or calibre, but on its ability to transmit its energy to the body while travelling through it.* If, for example, no exit hole was found and the bullet came to rest in the body, the conclusion must be that all of the energy with which the projectile was loaded when reaching the target was absorbed by the body. If a long narrow wound channel, in the absence of damage to large bones, was demonstrated, one might suspect a long-distance shot. With knowledge of the ammunition used and the extent of the injuries, such conclusions may be justified.

- *A long narrow wound channel can indicate different things:* it might mean, for instance, that signs of a temporary cavity will be recognized deeper in the body than usual, or that the bullet left the body before becoming unstable or deformed (see Section 7.2.3.1, 'Deformation/fragmentation'). It might be as a result of a short bullet fired by a handgun or the passage of a full-jacketed rifle bullet travelling relatively slowly.
- *A prominent temporary wound chamber does not necessarily equate to extensive injuries* – although this is often the case. It merely indicates that a significant amount of energy has been transferred to the body. If the tissue affected has the potential to cope with stretching and twisting, the consequences might be less severe than might otherwise be expected.

7.2.3 Some specifics of wound ballistics

7.2.3.1 Deformation/fragmentation

The deformation of a projectile travelling through a body is not necessarily merely an incidental result of being exposed to massive decelerating forces. Hunting bullets, for example, are designed to expand directly after skin penetration in order to increase the cross-sectional area and thereby enhance the transfer of energy from projectile to animal. In this case, the onset of the temporary cavity might start very early. Due to the rapid increase of the cross-sectional area of the deforming bullet at the very beginning of the wound channel, the narrow channel can be short or almost absent. The aim of hunting bullets is to guarantee the animal's instant death by maximally injuring vital organs. At the same time it is desirable to create an exit wound. In case of not succeeding in an instant kill, an exit wound bleeding to the outside is almost a prerequisite for retrieving the injured animal. Hence, despite the 'mushrooming' bullet deformation, the aim is to achieve a high penetration depth by maintaining the mass of the projectile, and fragmentation of the bullet is not necessarily welcome in this scenario. Exceptions to these requirements may be determined by specific needs. Beaver hunters try to avoid large exit wounds to maintain the quality of the fur without making concessions in terms of animal welfare. This is achieved by the use of splinter projectiles designed to fragment after impact (Parker *et al*., 2006).

Fragmentation, caused either by the bullet's design or by chance, increases the overall cross-sectional area, consequently increasing the volume of the temporary cavity. The mass of the original projectile can be reduced considerably (Fackler *et al*., 1984). The fragments are dispersed away from the axis of the main wound channel. Typically, the distribution of the fragments is cone-shaped and can be visualized by imaging techniques. On an X-ray image, the configuration of fragments of a high-velocity rifle projectile resembles a snowstorm. The longer penetration depth of larger and heavier fragments can be demonstrated, strengthening the evidential value of imaging techniques regarding the line of departure. However, these findings should be verified; for example, by necropsy. Steady linear embedding of bullet fragments into tissue does not necessarily occur and individual fragments might move from the localization into which they initially settled after the bullet disintegrated. 'Loose' fragments can follow the force of gravity, for instance, and be found at the bottom of body cavities, often embedded in blood clots, or can be moved due to vascular embolization. The secondary translocations of bullet fragments like these must, of course, be differentiated and be recorded as such. Furthermore, one should bear in mind that even slow-travelling projectiles, as shotgun pellets, can disrupt upon collision with, for example, bone (Frank, 1986).

Of course, the penetration depth of fragmented and non-fragmented projectiles cannot be compared.

7.2.3.2 Entrance and exit wound

Every external inspection of the animal will include a close examination of entrance and exit wounds. Though these generally are straightforward to distinguish, the assignment of each wound must be undertaken with care. It is the author's experience that entrance wounds in animals seldom show all the features described in standard literature referring to missile wounds in humans. This may be due to intrinsic differences, such as differing density of hair coat, or to the fact that close-distance shots are generally less frequent in animal cases compared with human shootings. The skin of dogs, pigs, sheep and goats are said to react most similarly to that of man (Schantz, 1979). Notwithstanding these possibilities for variation it remains meaningful to take a generic approach to describing the possible composition of entrance and exit wounds, as the wounding mechanisms are the same, regardless of species.

The entrance wound can be considered the first part of the wound channel. Its importance lies in being the first point of contact between the projectile and the body. The entrance wound potentially conveys valuable information about the angle of impact, characteristics of the bullet and the distance between the animal and the muzzle of the weapon. If shot from very close range, singeing of the fur or feathers may be present, but due to the splashing and oozing of blood in the wound area it can be very difficult to recognize.

The entrance wound may be the object of special interest regarding the occurrence of gunshot residues (GSR). To preserve GSRs, all handling of the wound area must be reduced to a minimum, and absolutely no cleaning of the wound should be undertaken uncritically (Karger, 2004)! Though autolysis, moisture, blood and contamination impede GSR analysis, the safest way of submitting an appropriate sample is to excise a larger skin area around the entrance wound (Di Maio, 1999). The intact wound with its encircling skin can then be stored frozen until processed further. In living animals, or if the entrance wound needs to remain with the body at necropsy, GSR can be sampled using cotton buds. On dry wounds, one can use cotton buds wetted with distilled water, tape-lifts or use a fine-toothed comb in the hair surrounding the wound (MacCrehan *et al.*, 2003). Examination for GSRs may be performed by, for example, scanning electron microscope (Karger, 2004) or energy dispersive X-ray (Di Maio, 1999).

At the margins of the entry wound, different zones merging into each other may be distinguished. The central penetration is caused by the bullet crushing the skin. A circular wound results when the angle of impact was perpendicular to the surface, while an elliptical wound is formed with a low angle of impact. As a consequence of loss of tissue substance the edges of the wound cannot readily be adapted. Again, tissue fragments from the skin are accelerated radially outwards from the central contact zone by the impact of the bullet. After having been stretched outwards, the elastic skin recoils somewhat, so that the entry wound is smaller than the calibre of the bullet. The edge and an area only a few millimetres wide around the entry wound form a ring of discolouration, due to abrasion and possible deposition of gunshot residues. The surface defect is a consequence of the displacement of debris from crushed tissue, as well as the radial acceleration and stretching of the skin caused by the entering bullet. The margin of distention, an outer reddened ring that merges into the unaffected skin, is characterized by multiple petechial sub-epithelial haemorrhages from lacerated capillaries.

Again, an asymmetric elliptical shape to these changes around the central perforation indicates a low angle of impact, with the larger tail pointing towards the shooter. The extent of the damage (as for the exit wound) does not convey detailed information about the bullet used, but it can indicate the amount of energy transferred at this point in the wound channel. There are many factors that can modify the configuration of the entrance wound from that described above, depending on different underlying physical mechanisms. A large irregular star-shaped wound might, for example, be seen when additional forces transmitted by propellant gases from a close-range shot affect the wounding process.

Skin penetration of an exiting bullet involves different mechanisms to those described for the entrance wound. In the majority of cases, the projectile has lost much of its energy and exposes a larger cross-sectional area when it hits the skin from the inside.

Consequently, the tissue is not crushed but buckled and stretched until the bullet is released by rupture of the skin. As no tissue substance is lost, the edges of the irregular-shaped wound can normally be adapted. If, meanwhile, the localization of the exit wound and the large temporary cavity coincide, loss of substance is obvious.

7.2.3.3 Shotgun

The wound picture created by shotgun pellets is largely determined by the range at which the weapon is fired. However, the design of ammunition used and the barrel characteristics are also important. These three factors determine how densely clustered is the sheaf of pellets just before reaching the point of impact.

A pellet sheaf and its ballistic can be compared with a herd of cattle that is to be driven through a river by cowboys. The cowboys determine how densely and how fast the animals move when the herd reaches the edge of the river. In a widely spread herd, the cows will go separately into the river, thereby slowing down, but still in a group that is heading in the same direction. If the herd stays close together, the first animals entering the water will slow down and, being crowded and pushed by the adjacent animals, will deviate sideways.

The wound channel of a close-range shotgun blast may have a larger diameter than the entrance hole, as the decelerated pellets, like the cattle from the example above, are deviated outwards by pellets clashing from behind. The light spherical pellets lose energy quickly and, consequently, the penetration depth of individual pellets generally declines rapidly with increasing range. Nevertheless, the penetration depth can still be considerable, markedly disrupting internal organs. The tissue damage of shotgun wounds, especially close-range wounds, can be extensive. At longer ranges, larger types of shot (size and weight of pellets) produce more serious injuries (Ordog *et al.*, 1988).

It is important to note that the morphology of the skin wound allows only a rough estimation of the shooting range. From shooting distances of around 3 m, differing characteristics of the barrel of the shotgun and the ammunition cause variation of the wound pattern. Generally, the shorter the distance, the denser will be the injuries of the entrance wound. If directly after leaving the barrel, the shot sheaf has not spread radially, it creates a single prominent circular wound. With rising distances and wider spreading of the shot sheaf, the edge of the wound starts to become undulating (*scalloping*) or discrete skin perforations caused by individual pellets are seen immediately peripheral to the central wound. With still wider spread (or larger distance) the larger central wound is not present and instead a wound field composed of many individual pellet perforations is found.

The range estimation is based on the wound pattern as long as a central wound is apparent, but is based on the dispersion pattern of the pellets at longer ranges. Correctly scaled documentation of a representative wound field, showing all points of impact within that field, is necessary to compare the pattern in question to the test-shot pattern fired with the same weapon and ammunition. The resulting range estimation would presuppose that the test field was within the core area of the shot sheaf and that the angle of impact was perpendicular (Karger, 2004).

This may illustrate that detailed statements about shooting distances should only be made with caution, and should include a statement of the underlying preconditions.

Shotgun pellets can be made of many different metal alloys, such as lead, steel, tungsten-bismuth-tin (TBT) and other principal constituents. A first impression of what material the shotgun pellet is made of can be achieved by studying the radiological images (see Section 7.2.4.1, ‘Before necropsy’). However, true and detailed information is based on the recovery of the pellets. Besides studying obvious injuries, one should pay attention to possible reactions of the surrounding tissue of each recovered pellet. Kraabel *et al.* (1996) observed a consistent inflammatory response to steel pellets in mallard muscle tissue, a reaction possibly triggered by corrosion. TBT pellets induced comparatively mild inflammatory responses. Sterile steel shots surgically implanted into dogs corroded and resulted in severe inflammatory responses, sometimes complicated by bacterial contamination and foreign-body reactions (Bartels *et al.*, 1991). Species-specific differences in the responses must be taken into account. Tungsten alloy pellets, for instance, implanted intramuscularly into rats, induced growth of aggressive, rapidly metastasizing high-grade pleomorphic rhabdomyosarcomas in an experimental study (Kalinich *et al.*, 2005).

Sampling of tissue in a state of inflammation or granulation provides an opportunity for approximation of age of the process (Schulz, 1990; Wohlsein and Reifinger, 2011).

7.2.3.4 Airgun

Though air weapons are commonly considered toys, or at least non-lethal weapons, projectiles from air-powered guns cause injuries and fatalities (Smith, 1985; Bond *et al.*, 1996; Campbell-Hewson *et al.*, 1997; Milroy *et al.*, 1998). These weapons have been shown to be dangerous devices for humans and animals, and animals wounded by airguns are relatively frequently presented in veterinary clinics (Cooper and Cooper, 2007; Anon., 2013). Even pellets fired from a comparatively low-powered weapon, such as a ball-bearing gun, can penetrate human skin. Such an injury is reported by Tsui *et al.* (2010). A 15-year-old boy suffered from an infected wound caused by a spherical soft airgun pellet, 0.2 g in weight and 6 mm in diameter, discharged from legal weapons with muzzle energy not greater than 2 Joule. Other authors (Phillips, 1979; Sinclair *et al.*, 2006; Cooper and Cooper, 2007; Merck, 2007; Munro and Munro, 2008; de la Fuente *et al.*, 2013) discuss the ability of airgun pellets, usually .177 calibre (4.5 mm) with a law-regulated maximum muzzle velocity of maximal 7.5 Joule,[1] to penetrate human skin or the cornea of the human eye. Penetration depth in ballistic gel close to 8 cm for 5.5 mm pellets fired from 10 m range has been reported by Ogunc *et al.* (2013). As in anthropocentric forensics (Bond *et al.*, 1996), veterinarians should no longer underestimate the potential for life-threatening injury from these weapons.

As stated above, generalization across species is problematic, as both general anatomical differences and absolute differences can be distinct. The skin of birds is, for instance, generally far thinner than mammal skin (Vollmerhaus *et al.*, 1992), not to mention the vast proportional differences between humans and, for example, a budgerigar with a body weight of 45 g. Wightman *et al.* (2013) mounted fresh skin samples of different animal species on blocks of gelatin to test the effect of the skin on the perforation ability of airgun pellets; chicken skin had no effect, pig skin stopped the pellet and cow skin was perforated by the pellets.

Small calibre and light weight of airgun pellets must not be equated with being innocuous. After discharge, the velocity of the projectiles decreases rapidly and the sectional density of the pellets is comparatively low. There is a need for a high muzzle velocity to counteract these ballistic disadvantages. Therefore, unless the anatomical structures at the point of impact are very delicate, the barrel–target distance must be relatively short to cause serious injuries (Missliwetz, 1987; Kneubuehl *et al.*, 2011). Nevertheless, the transmitted energy can be significant enough to fracture the upper arm bone (Phillips, 1979) or to cause a traumatic cervical spinal cord injury (de la Fuente *et al.*, 2013) in a cat. Indeed, cone-shaped steel pellets are documented to have penetrated 1 mm-thick steel plates (Smith, 1985).

The wound ballistics of air weapon projectiles follows the mechanisms described above. However, bruises and other injuries without penetration of the skin may be considered a blunt trauma, rather than a gunshot wound. The pathoanatomical findings may be delicate and may easily remain undetected, even by the owners of affected animals. In a study of injured urban cats and dogs, as many as 16 out of 19 owners did not suspect a previous shooting incident when veterinary examination discovered their pet to be carrying a small-calibre projectile (Keep, 1970). This may be a consequence of a small-sized entrance wound, a small calibre of the narrow channel and, in many cases, the absence of an exit wound. In this context, radiographic examination is very valuable, especially for the detection of older damage.

The picture of the wound channel at necropsy is dominated by the appearance of crushed tissue and only moderate bleeding. It should be carefully explored along its total length, especially as some types of air-weapon ammunition are embedded in radiolucent components (sabot) (Smith, 1985). These might be found as a fragment within the wound channel and must be preserved as evidence.

Airgun pellets and remains must, of course, be preserved using standard routines. The secured item can be assigned to the respective type of ammunition. For the forensic veterinarian, knowledge of the design of the bullet and composition material are necessary to obtain the best possible picture of the shooting event. In combination with anatomical findings – such as location of the point of impact, penetration depth and type of tissue along the wound path – these ballistic specifications can help investigators to form an impression of, for instance, the range of the shot (Missliwetz, 1987). By comparing three different types of airgun pellets, Smith (1985) observed distinct differences in penetration depth in ballistic gel, and a more recent British study indicates total penetration depth of gelatin and different animal organs to be around 10–15 cm (Wightman *et al.*, 2013).

The design of the tip and the material from which the pellet is made may not only be of value for the investigation, but will have a great influence on the capability of the projectile to penetrate tissue (Smith, 1985).

7.2.4 Essential steps of investigating a shot animal

7.2.4.1 Before necropsy

The immediate priority in the investigation of a surviving shot animal is to administer appropriate first-aid treatment before processing potential evidence from the animal or scene. But even in challenging situations, a well-structured approach is obligatory for all forensic work, a *sine qua non* for the forensic veterinary investigator! The evidence with which we are working has a constantly changing dynamic character. Alterations of potential evidential value in a living animal might be changed by necessary clinical treatment, secondary healing, or the animal's behaviour (licking of the wound, etc.). Carcasses change due to autolytic processes. Necropsy, as clinical treatment, is an evidence-destroying investigative method. Even when circumstances suggest a rapid response, one should consider spending time on documentation or preservation of evidence. In any case, each step must be carefully considered to ensure correct procedure.

Extensive transfer of information from the crime scene prevents misinterpretation of observations made in the clinic or the necropsy hall. If one does not have the chance to attend the crime scene oneself, one should try to collect as much information as possible by interviewing those involved in the investigation at the scene. Information on who might be the most relevant person(s) to talk to might be found on the chain of custody scheme or from the officer with overall responsibility for the crime scene.

Certain general questions need to be addressed in cases involving the use of weapons: How many shots were fired and from how many weapons? How many victims were there, receiving how many hits each? Did crime scene findings (for example, the blood stain pattern) or the localization of the victims indicate a connection to the wound pattern?

Questions specific to each body would be: In what position was the body found? What kind of injuries were there and were there injury-related marks? An example would be the establishment of consistency between the body and surface alterations. If an animal was lying on the ground when it received a *coup de grâce*, one could expect the exiting bullet to cause damage on the underlying surface. One should be aware of the possibility of a residual projectile when removing the body. The missile could be embedded in the ground or within the fur, or could even have re-entered the body. The latter event could involve an atypical entrance wound on which the uninformed veterinary forensic examiner may expend unnecessary time and resources attempting to form an opinion.

Preliminary first impression conclusions from an adspective on-scene examination of the body might also initiate other types of forensic investigations. For instance, a star-shaped wound in the head indicating a short muzzle-to-target distance would prompt a recommendation to look for backspatter of blood and tissue debris on a suspect's clothing or weapon.

Whenever bullet wounds or other trauma are suspected, the animal should be imaged as soon as possible. Instead of using conventional radiography, one might consider a computer tomographic (CT) examination. In human forensic pathology, imaging techniques such as CT, magnetic resonance imaging (MRI) and 3D surface scanners, resulting in three-dimensional imaging, are increasingly integrated into the investigations, especially within trauma diagnostics. Post-mortem CT has been shown to be superior to autopsy for depicting fractures and locating projectiles or foreign objects (Flach *et al.*, 2014). CT facilities are nowadays widely available and when an animal carcass is sealed in a body bag the requirements of working in an environment governed by human health standards can be observed. For detecting non-opaque items like soft gun pellets, undetectable on X-ray images, ultrasonographic examination is particularly useful (Tsui *et al.*, 2010).

The most outstanding advantage implied using 3D-imaging techniques is the creation of a data set documenting the anatomical proportions within a whole body. This is done time-effectively and without the need to manipulate the evidence by a destructive method (Flach *et al.*, 2014). Structures with deviant density, like a wound channel, can be visualized against a variety of denser structures, such as parenchymal organs and muscles. Bullets or bullet fragments can be identified by their exceptionally high density. The data set can be re-processed and re-assessed at any time, enabling accurate measurements. Presentation of complex changes, that court and jury might otherwise be challenged to understand by verbal description alone, can be facilitated. A bullet wound channel, for example, can be more clearly demonstrated via the clear narrative of CT images (see Box 7.2.1., 'Illegal shooting of wild grey wolf').

The benefits of 3D imaging has enhanced cooperation between radiologists and pathologists (Flach *et al.*, 2014), resulting in the development of the specialism named 'virtopsy', which has shown to be of high value, especially in wound ballistics.

Information from the crime scene and from imaging provide a solid foundation when the forensic veterinarian, whether clinician or pathologist, approaches the investigation of a shot animal. Nevertheless, all these findings need to be recorded by detailed documentation.

7.2.4.2 The practical approach

After having gone through the routine of the external examination, the next step is to focus on the documentation of entrance and exit wounds. For most cases, the line of departure is of special interest. In almost all cases, it provides a strong indication of position of the weapon in relation to the victim. The entrance and exit wounds are the only outer sign of the axis along which the projectile moved. The axis needs to be measured and documented before the invasive part of the necropsy, which will alter the normal relative positioning of the body, proceeds. An estimation of the line of departure based on the position of the entrance and exit wound alone must be considered as preliminary, since the bullet might have changed its direction within the body (see Section 7.2.2, 'Basics of wound ballistics'). Consequently, statements concerning this matter should not be made without verification.

If the animal was hit by several shots, entrance and exit wounds must be aligned. If there is doubt, then all possible permutations must be considered and documented. It is an advantage for the clinicians and pathologist over the radiologist that he can easily manipulate the animal into a variety of different positions to verify a working hypothesis (see Figs 7.2.6 and 7.2.7). Care must be taken, however, not to place the animal in an unnatural body position. This would apply when attempts are made to trace a wound channel on a suspended body in the necropsy room. The body would be stretched and consequently the tracing risks resulting in an exaggeratedly acute angle of shot.

Box 7.2.1. Illegal shooting of wild grey wolf

By combining the documentation achieved by the use of different methods (necropsy and CT-imaging), strong and illustrative evidence could be presented to the court.

In August 2011 the shooting of a grey wolf was reported. A claim of legal self-defence during protection of fenced domestic sheep was made by the defence. Necropsy confirmed that the animal had been shot. The angle of incidence was estimated to be between 0° and 10° from the front-right side. The findings

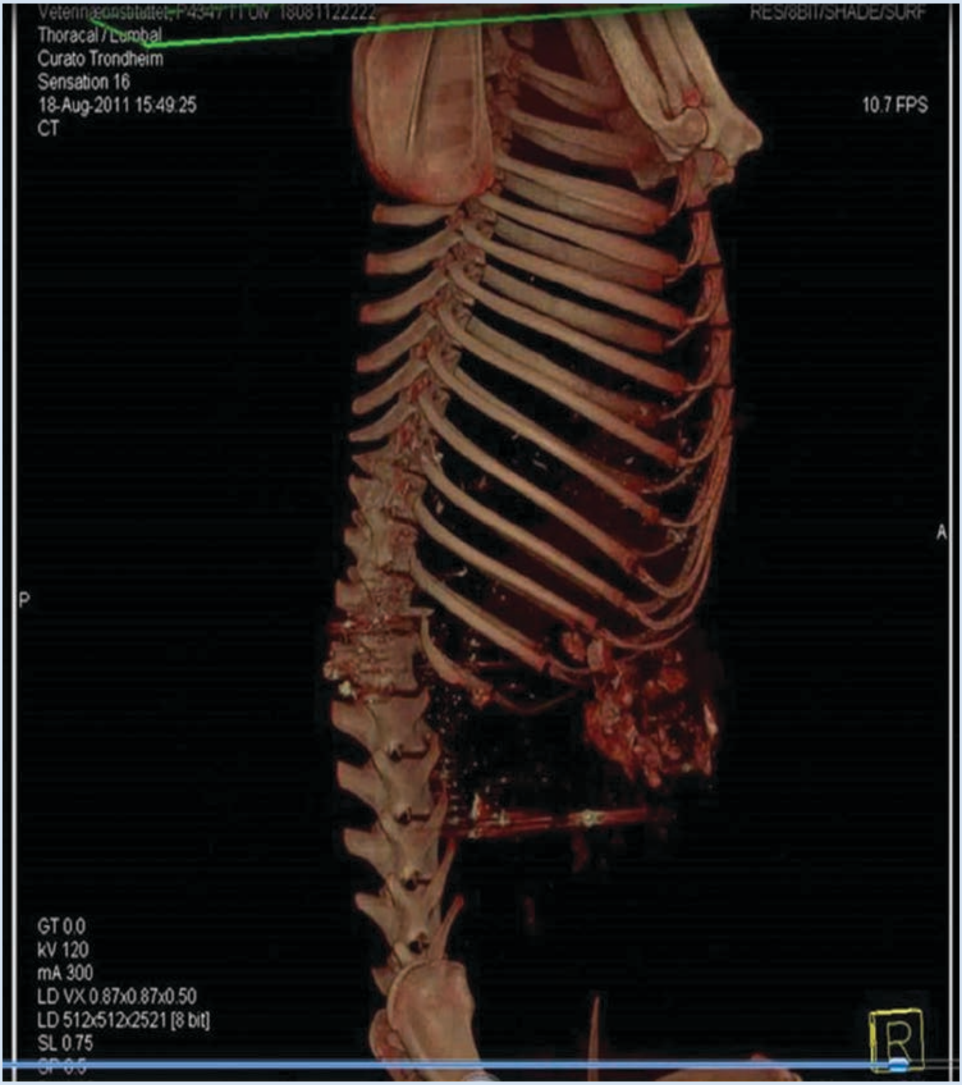

Fig. 7.2.2. Overview picture from lateral aspect of grey wolf (*Lupus lupus*), showing the thorax and luminal skeleton.

Continued

Box 7.2.1. Continued.

were in contradiction to the statement of the shooter. The prosecution appraised the angle of incidence as being crucial to the case. Data from the pre-necropsy whole-body computer tomographic examination was processed with the aim of a best possible demonstration and verification of the wound channel. The narrow channel through the back muscles could be visualized and its angle to the spinal column was measured. The result confirmed previous examinations and added valuable material for the courtroom presentation.

Figures 7.2.2–7.2.5 are from a video presentation made for courtroom demonstration. In Figs 7.2.2 and 7.2.3, there are fractures with loss of bone substance of the caudal four ribs. The wound is funnel-shaped; there are projectile fragments (bright spots) in the wound area. Each fragment on its own renders imprecise estimation of the axis of travel of the projectile before fragmentation. In Fig. 7.2.4, the entrance wound is seen in the upper part of the picture. Before the bullet fractured the 10th rib, it passed three more cranial ribs and their intercostal spaces. This part of the wound channel is not visible. Figure 7.2.5 shows the narrow channel between the entrance wound and fracture of the 10th rib. The perforation of the entrance wound is slightly out of focus and peripheral muscle layers are likely to be located 'out of axis', due to their sliding over the deeper muscles. Thus this outer part of the wound channel is less suitable for the estimation of the angle of incidence and was consequently discounted when the angle between the narrow channel and the spine was measured.

The Norwegian Øvre Romerike tingrett (district court) sentenced the shooter to four months' imprisonment for shooting a grey wolf in claimed self-defence and thereby deliberately violating the right of self-defence.

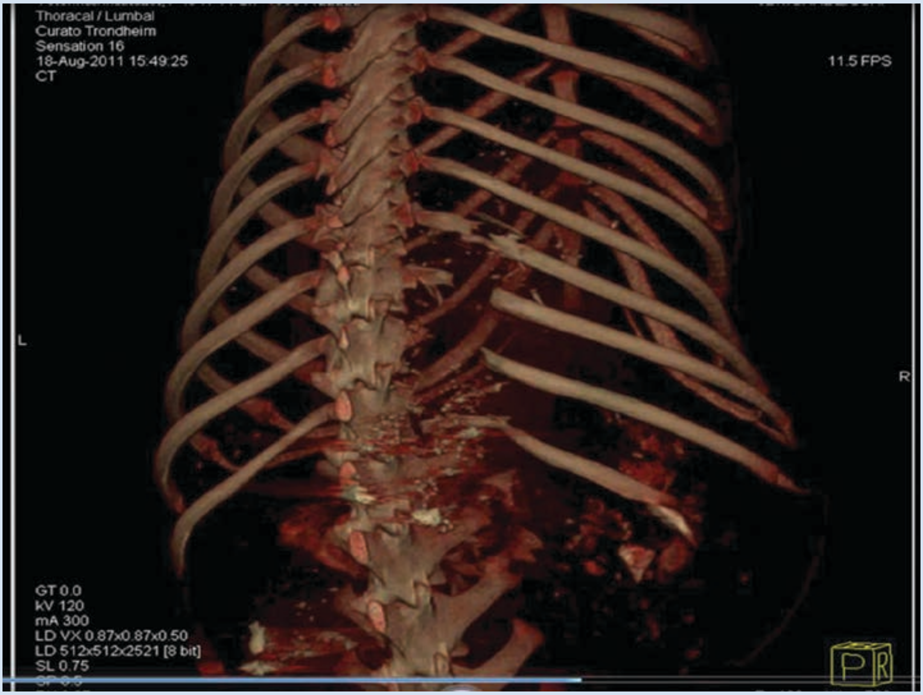

Fig. 7.2.3. Magnification of the image shown in Fig. 7.2.2, now showing caudal thorax and cranial lumbar vertebrae from mainly posterior aspect.

Continued

Box 7.2.1. Continued.

Fig. 7.2.4. Hairless body surface of the same section as in Fig. 7.2.3 and viewed from the same perspective.

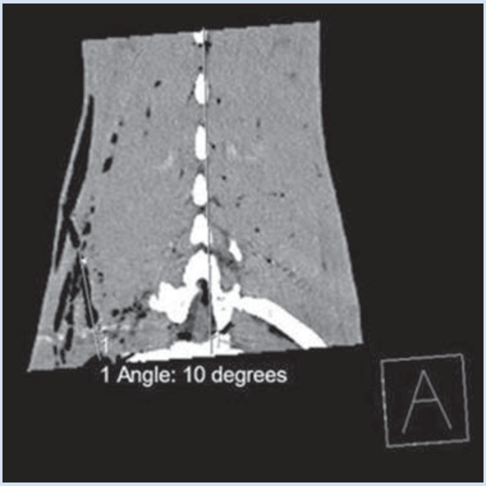

Fig. 7.2.5. Visualization of the narrow channel between the entrance wound and fracture of the 10th rib, viewed from a precise anterior aspect.

Figs 7.2.6 and 7.2.7 show a wounded bear. In Fig. 7.2.7, the probe remains in the same relationship to the wound as that shown in Fig. 7.2.6, but now a possible, near horizontal trajectory of the projectile that caused the injury can be appreciated, and approximations of the angle of shot and line of departure can be achieved.

The first part of the wound channel – the narrow wound channel – potentially yields the most reliable information regarding the angle from which the animal was shot. This portion of the total wound channel may show the best consistency between the axis on which the projectile travelled before and after hitting the target. In order to utilize this information, three conditions must be ensured.

First, the narrow channel must be localized within a part of the body that justifies conclusions regarding the animal's position the moment it was shot. Usually there is a demand to comment on the general position of the animal in relation to the shooter. In this context, the longitudinal axis of the body represented by the spinal column of the trunk is the most appropriate marker for the position of the animal. Parts that have a high degree of freedom such as the tail, the distal extremities and the head and neck region are consequently less reliable than the trunk.

Second, the narrow channel must be long enough that its axis can be estimated with a sufficient degree of certainty. Finally, one must succeed in elucidating and documenting the path of the narrow channel. There are a number of factors which may confound demonstration of the narrow channel. For instance, it may not be possible using modern imaging techniques to demonstrate a collapsed wound channel; the true axis of the channel might not be consistent with the estimated route documented before the body was opened. At necropsy, the carcass may be in a state of advanced autolysis, softening the tissue around the narrow channel. While investigating the wound, extreme care must be taken that the instrument is not inadvertently extended beyond the confines of the narrow channel.

Fig. 7.2.6. A brown bear (*Ursus arctos*) lying in right lateral position enabling a standard left-sided procedure. The probe indicates the longitudinal axis of the wound channel. Entrance wound on the left side of the picture.

Fig. 7.2.7. The same animal as in Fig. 7.2.6, now mounted in a close to natural, ventrodorsal position with vertical forelegs and head and neck bent to the right.

7.2.4.3 Recovery of bullets

Bullets or relevant fragments recovered from the body must be considered as evidence and must be routinely preserved using standard techniques. They contain valuable information for the case and for the examiner. Submitted to a ballistic lab more information can be revealed from further examination. Determination of the calibre, distinction between rifle and handgun, the linking of the projectile to an individual weapon or type of weapon, and/or establishing contact of the bullets with intermediate target before entering the body, are examples (Brinkmann and Madea, 2004).

Some cast-iron rules must be observed in the process of missile recovery (Wobeser, 1996; Walker and Adrian, 2003; Brinkmann and Madea, 2004).

- Care must be taken not to cut the bullet while dissecting in the proximity of the projectile.
- No tissue must be discarded until the projectile is recovered. If tissue is removed from the body it should be arranged in a logical manner nearby. If not succeeding in localizing the projectile, one can re-examine piece by piece by palpation or X-ray.
- Bullets must not be handled with metal forceps or other metallic surgical instruments in order to avoid alteration of the fragile markings on the surface of the bullet. Sterile single-use forceps are established tools for this procedure, though Di Maio (1999) recommends removal of bullets with fingers. Preliminary measurements can be taken using a plastic vernier caliper.
- To avoid cross-contamination, clean instruments must be used for each piece of evidence.
- Bullets should be washed to remove tissue and blood. The use of fresh running water will be sufficient in most cases but, if special washing procedures need to be followed, temporary storage at −20°C without washing is preferable.

- The recovered bullet should be briefly described by recording general appearance, deformation/non-deformation, approximate calibre, full- or semi-jacketed, weight, magnetic properties, etc.
- The dried bullets should be placed in wadded packaging (Fig. 7.2.8) and paper envelope for storage or submission.
- It is sufficient to recover a representative sample of pellets from shotgun wounds (Di Maio, 1999). Redundant pellets may be used for preliminary tests, such as testing for magnetism or flame tests.
- Fillers (felt wads, plastic cups, plastic crosspieces, etc.) should be handled in a similar manner to bullets.

Early information about the projectile(s) that are to be recovered is normally based on the assessment of radiographs, pictures or other images. If the recovered projectile matches the imaged structure, that circumstance should be recorded and in due course marked on the picture. It will differ from case to case, whether bullet removal is best performed by dissecting along the wound track or by more direct approach. At all steps of examination, one should consider the need to take (preliminary) tests, such as flaming, assessing magnetism or swabbing, if a local infectious condition is suspected. Definitive examination of recovered projectile(s) or fragments should be performed at the ballistic lab or at a later phase of the investigation.

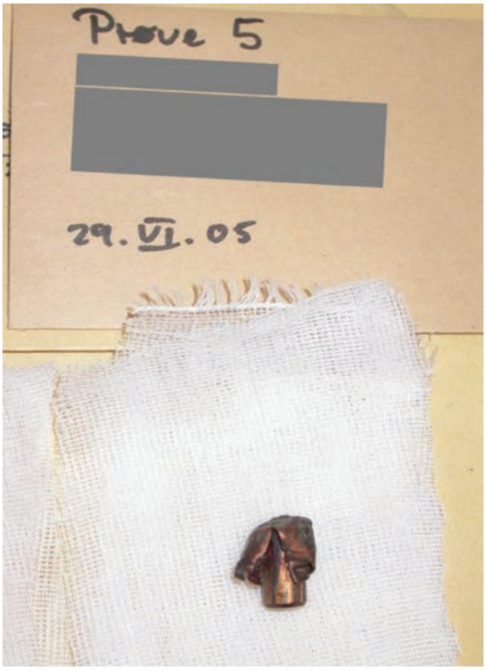

Fig. 7.2.8. The dried bullets should be placed in wadded packaging and paper envelope for storage or submission.

It is necessary to know about the further steps of examination regarding each bullet before it is actually removed. Generally, it is a good practice to wash the projectile under fresh running water (Walker and Adrian, 2003). This ensures that the surface of the bullet is cleaned and tissue and blood cannot harden on it. This procedure is contraindicated if the bullet is to be examined for gunshot residues, however, or for all kinds of foreign debris, such as textile fibres, or mineral and biological materials (Walker and Adrian, 2003). To save residues, which may be fragments or soft tissue of intermediate targets, the projectile must undergo special procedures of washing and filtration (Nichols and Sens, 1990). Preservation of traces is possible even with a bullet recovered outside the body after completely traversing the body – a so-called 'through and through' shot. Karger *et al.* (1996) succeeded in DNA typing cellular debris sampled from hollow point and full-metal-jacket bullets after full penetration of calves, and achieved successful individualization on the basis of STR loci in three human cases (Karger *et al.*, 1997). It is possible also to perform cytological examinations (Nichols and Sens, 1990; Karger, 2004). It can be expected that the amount of gunshot residue obtainable from semi-jacketed and hollow-point bullets is larger than from full-jacket projectiles (Karger *et al.*, 1996).

7.2.5 Conclusion

The appearance of wounds caused by different types of projectiles may range from clear to chaotic. Nevertheless, all modifications are a consequence of the impact of forces falling under the same laws of physics, a consequence of action and reaction. The knowledge about what a bullet does to the body and what the body does to the bullet is crucial for surgeons and pathologists to unscramble – at least parts of – the traumatic modifications they are confronted with when working with animals being fired upon. Hence, being acquainted with the basics of wound ballistics is indispensable to high-quality forensic work.

Case Study 7.2.1. Cat shot by air rifle by David Bailey (images courtesy of Adele Wharton)

Figures 7.2.9a and 7.2.9b show an overview and close-up view of a cat that had been shot by an air-rifle pellet, with an entry wound mid-abdomen. Figs 7.2.9c and 7.2.9d demonstrate massive disruption to the left stifle joint, with the deformed pellet still visible in the radiograph.

It is posited that this animal was lying at rest when it was shot from a cranial direction. The amount of damage done to the stifle joint suggests a close contact discharge.

Fig. 7.2.9. The cat shown in (a) to (d) has been shot by an air-rifle pellet.

Continued

Case Study 7.2.1. Continued.

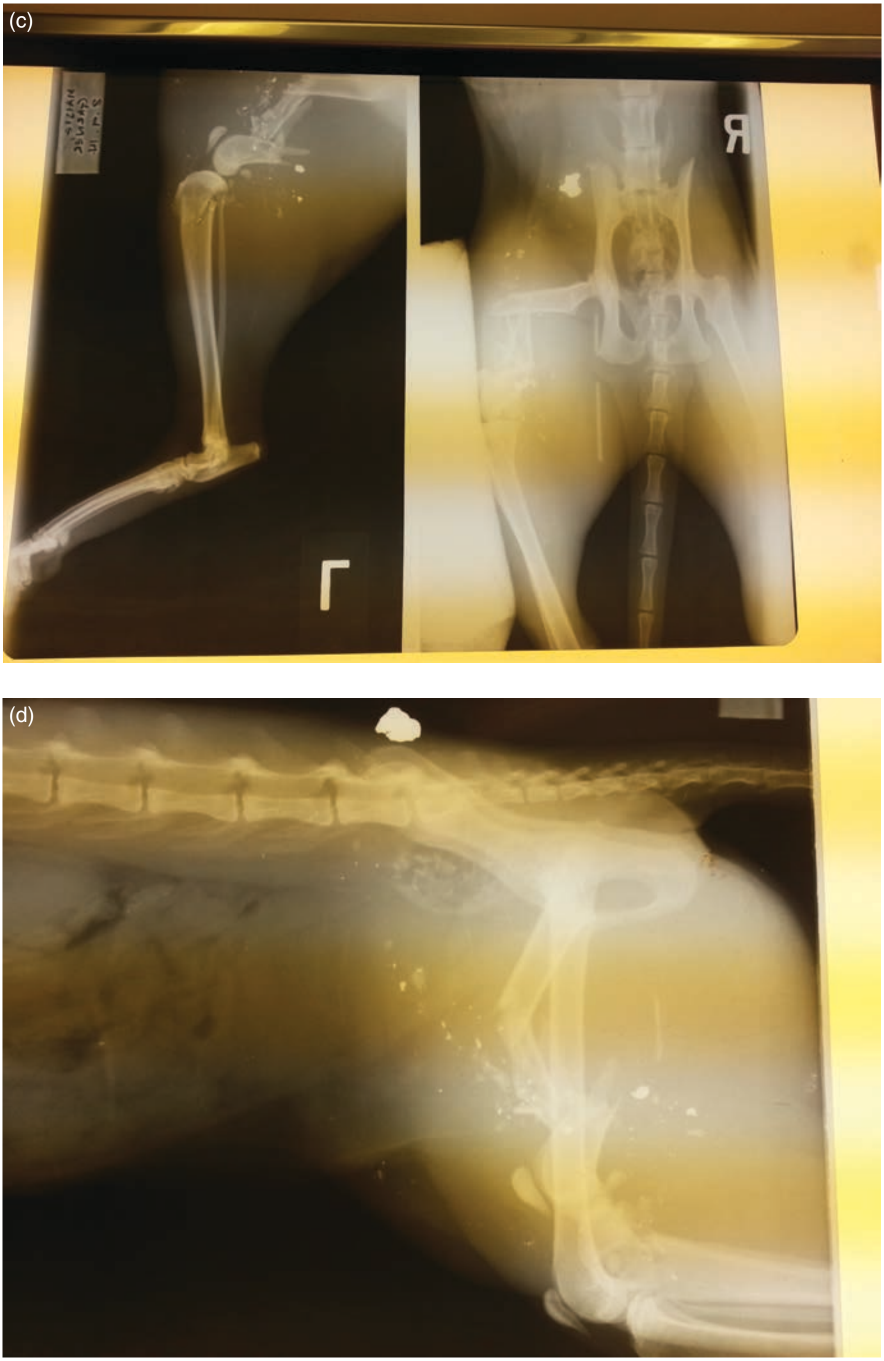

Fig. 7.2.9. Continued.

Note

[1] The specific regulation differs widely between countries. In the UK air weapons are, for the time being, regulated by law to below 12 ft lb (16.3 J) for air rifles and below 6 ft lb (8.1 J) for air pistols (Wightman *et al.*, 2013).

References

Anon. (2013) *Animal Welfare in Scotland*. Available online at: http://www.onekind.org/uploads/publications/animal-welfare-report-2013.pdf (accessed 29 December 2014).

Bartels, K.E., Stair, E.L. and Cohen, R.E. (1991) Corrosion potential of steel bird shot in dogs. *Journal of the American Veterinary Medical Association* 199, 856–863.

Bond, S.J., Schnier, G.C. and Miller, F.B. (1996) Air-powered guns: too much firepower to be a toy. *Journal of Trauma and Acute Care Surgery* 41, 674–678.

Braathen, E., Moen, E. and Lien, J. (2006) *Ladeboken,* 6th edn. HM-Nordic, Oslo, Norway.

Brinkmann, B. and Madea, B. (2004) *Handbuch Gerichtliche Medizin*. Springer, Berlin, Germany.

Campbell-Hewson, G., Egleston, C. and Busuttil, A. (1997) The use of air weapons in attempted suicide. *Injury* 28, 153–158.

Cooper, J.E. and Cooper, M.E. (2007) *Introduction to Veterinary and Comparative Forensic Medicine*. Blackwell, Oxford, UK.

de la Fuente, C., Ródenas, S., Pumarola, M. and Añor, S. (2013) Dural tear and myelomalacia caused by an airgun pellet in a cat. *The Canadian Veterinary Journal* 54, 679–682.

Di Maio, V.J.M. (1999) *Gunshot Wounds: Practical Aspects of Firearms, Ballistics, and Forensic Techniques,* 2nd edn. CRC Press, New York, USA.

Fackler, M.L. (1987) What's wrong with the wound ballistics literature, and why. Available online at: http://www.rkba.org/research/fackler/wrong.html (accessed 27 March 2015).

Fackler, M.L., Surinchak, J.S., Malinowski, J.A. and Bowen, R.E. (1984) Bullet fragmentation: a major cause of tissue disruption. *Journal of Trauma* 24, 35–39.

Flach, P.M., Thali, M.J. and Germerott, T. (2014) Times have changed! Forensic radiology – a new challenge for radiology and forensic pathology. *American Journal of Roentgenology* 202, W325–334.

Frank, A. (1986) Lead fragments in tissues from wild birds: a cause of misleading analytical results. *Science of the Total Environment* 54, 275–281.

Kalinich, J.F., Emond, C.A., Dalton, T.K., Mog, S.R., Coleman, G.D., Kordell, J.E., Miller, A.C. and McClain, D.E. (2005) Embedded weapons-grade tungsten alloy shrapnel rapidly induces metastatic high-grade rhabdomyosarcomas in F344 rats. *Environmental Health Perspectives*, 729–734.

Karger, B. (2004) Schussverletzungen. In: Brinkmann, B. and Madea, B. (eds) *Handbuch gerichtliche Medizin*. Springer Verlag, Berlin, Germany, pp. 593–682.

Karger, B., Meyer, E., Knudsen, P.J.T. and Brinkmann, B. (1996) DNA typing of cellular material on perforating bullets. *International Journal of Legal Medicine* 108, 177–179.

Karger, B., Meyer, E. and DuChesne, A. (1997) STR analysis on perforating FMJ bullets and a new VWA variant allele. *International Journal of Legal Medicine* 110, 101–103.

Keep, J.M. (1970) Gunshot injuries to urban dogs and cats. *Australian Veterinary Journal* 46, 330–334.

Kneubuehl, B.P., Coupland, R.M., Rothschild, M.A. and Thali, M.J. (2011) *Wound Ballistics: Basics and Applications*. Springer, Berlin, Germany.

Kraabel, B.J., Miller, M.W., Getzy, D.M. and Ringelman, J.K. (1996) Effects of embedded tungsten-bismuth-tin shot and steel shot on mallards (Anas platyrhynchos). *Journal of Wildlife Diseases* 32, 1–8.

MacCrehan, W.A., Layman, M.J. and Secl, J.D. (2003) Hair combing to collect organic gunshot residues (OGSR). *Forensic Science International* 135, 167–173.

Merck, M.D. (2007) *Veterinary Forensics*. Blackwell, Oxford, UK.

Milroy, C.M., Clark, J.C., Carter, N., Rutty, G. and Rooney, N. (1998) Air weapon fatalities. *Journal of Clinical Pathology* 51, 525–529.

Missliwetz, J. (1987) Zur Grenzgeschwindigkeit bei der Haut. *Beiträge zur gerichtlichen Medizin* 45, 411–432.

Munro, R. and Munro, H.M.C. (2008) *Animal Abuse and Unlawful Killing*. Saunders Elsevier, Edinburgh, UK.

Nicholas, N. and Welsch, J. (2004) *Ballistic Gelatin*. Available online at: http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA446543 (accessed 27 March 2015).

Nichols, C.A. and Sens, M.A. (1990) Recovery and evaluation by cytologic techniques of trace material retained on bullets. *The American Journal of Forensic Medicine and Pathology* 11(1), 17–34.

Ogunc, G.I., Ozer, M.T., Eryilmaz, M., Karakus, O. and Uzar, A.I. (2013) The wounding potential and legal situations of air guns – experimental study. *Australian Journal of Forensic Sciences* 46, 39–52.

Ordog, G.J., Wasserberger, J. and Balasubramaniam, S. (1988) Shotgun Wound Ballistics. *Journal of Trauma and Acute Care Surgery* 28, 624–631.

Parker, H., Rosell, F. and Danielsen, J. (2006) Efficacy of cartridge type and projectile design in the harvest of beaver. *Wildlife Society Bulletin* 34, 127–130.

Phillips, I.R. (1979) A survey of bone fractures in the dog and cat. *Journal of Small Animal Practice* 20, 661–674.

Schantz, B. (1979) Aspects on the choice of experimental animals when reproducing missile trauma. *Acta chirurgica Scandinavica Supplementum* 489, 121–130.

Schulz, L.-C. (1990) *Lehrbuch der Allgemeinen Pathologie*. Enke, Stuttgart, Germany.

Sinclair, L., Merck, M.D. and Lockwood, R. (2006) *Forensic Investigation of Animal Cruelty,* 1. Humane Society Press, Washington, DC, USA.

Smith, W.D. (1985) Air rifle ammunition and its influence on wounding potential. *Archives of Emergency Medicine* 2, 25–29.

Tsui, C., Tsui, K. and Tang, Y. (2010) Ball bearing (BB) gun injuries. *Hong Kong Journal of Emergency Medicine* 17, 488.

Vollmerhaus, B., Sinowatz, I., Frewein, J. and Waibl, H. (1992) *Anatomie der Vögel,* 2. Verlag Paul Parey, Berlin, Germany.

Walker, N.D. and Adrian, W.J. (2003) *Wildlife Forensic Field Manual,* 3. Association of Midwest Fish and Game Law Enforcement Officers, Denver, Colorado, USA.

Wightman, G., Cochrane, R., Gray, R.A. and Linton, M. (2013) A contribution to the discussion on the safety of air weapons. *Science & Justice* 53, 343–349.

Wobeser, G. (1996) Forensic (medico-legal) necropsy of wildlife. *Journal of Wildlife Diseases* 32, 240–249.

Wohlsein, P. and Reifinger, M. (2011) Todeszeichen und Wundalterbestimmung. In: Baumgärtner, W. and Gruber, A.D. (eds) *Allgemeine Pathologie für die Tiermedizin*. Enke Verlag, Stuttgart, Germany, pp. 342–358.