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

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.

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).

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 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), deactivated (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

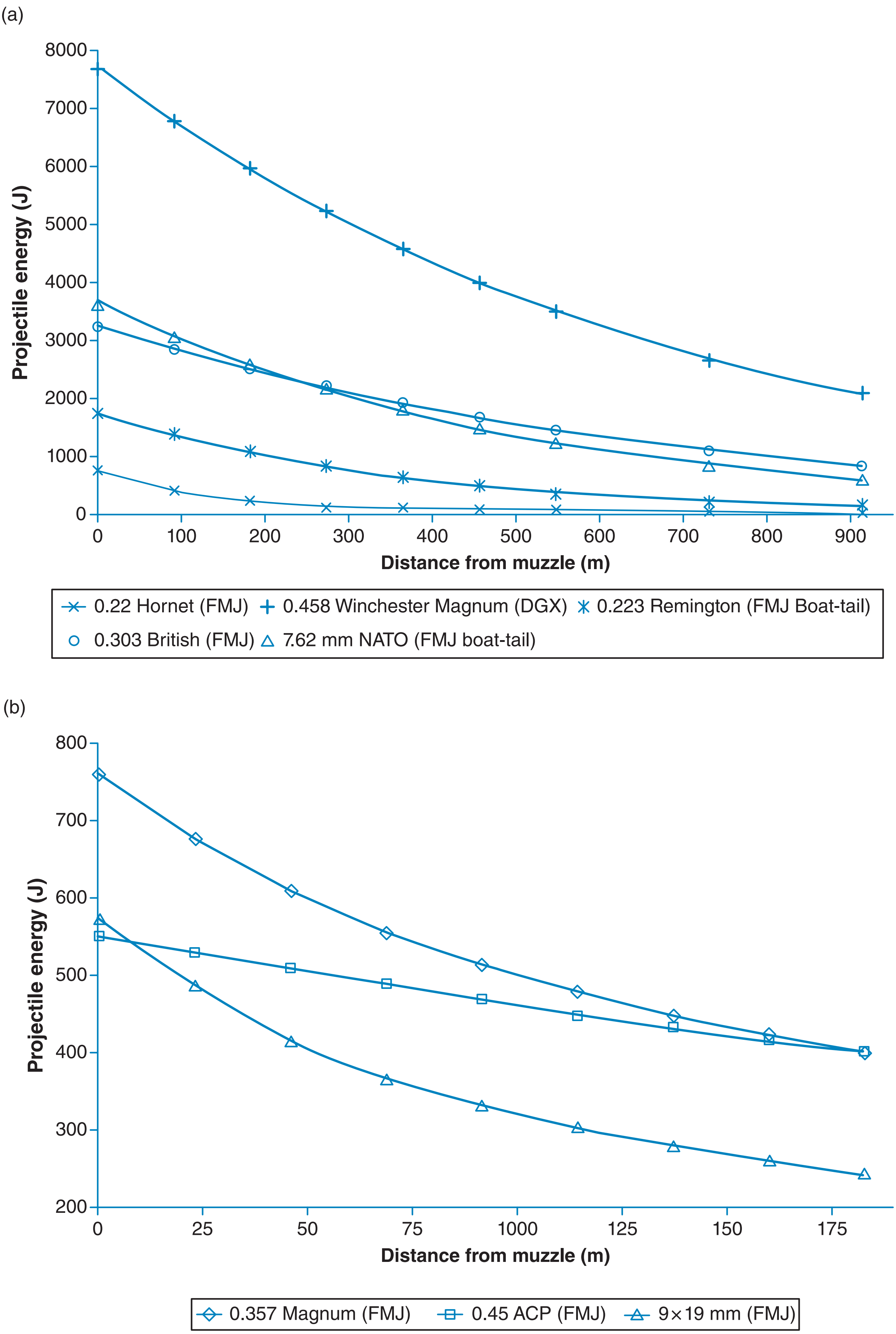

Fig. 7.1.2. Projectile energy changes for some common cartridges.

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.