Ballistics Primer

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1. Introduction and Scope

The aim of this primer is to present:

1. A scientific understanding of current practice for Forensic Ballistics and Gunshot Residue examination used within a forensic science context.

2. Guidance to the Judiciary in relation to the strengths and limitations of current interpretation and evaluations which can be made, in particular (a) the elements of the work which are subjective in nature, and (b) the linking of bullets and cartridge cases to a specific weapon.

The primer has been laid out in sections providing the basic information relating to the different elements of firearms and gunshot residue (GSR) analysis used in forensic science.

In addition, the Primer includes references highlighting areas for further reading, appendices and a glossary of terms.

Ballistics is the study of projectiles in flight; the word is derived from the Greek, *ballein*, meaning "to throw". Forensic Ballistics is commonly accepted as any scientific examination relating to firearms and performed with the intention of presenting the findings in court. This commonly includes providing an opinion as to whether the ammunition components may be linked to the weapon which discharged them, establishing range of fire, identifying entry and exit wounds, interpreting damage caused by gunshots and examining the mechanical condition of guns. Ironically, calculating the properties of a bullet or projectile in flight, true ballistics, is hardly ever used, although in some rare cases it is a vital part of the firearms expert's armoury. Somewhat unusually in forensic science in the United Kingdom, ballistic experts are expected to give opinions on the classification of firearms, under the many pieces of complex firearms legislation.

The study of Gunshot Residue, or GSR, is normally regarded as a discipline separate from forensic ballistics but it is closely linked, and within the scope of this Primer.

History

In some interesting early examples, interpretation of material recovered following a shooting was used to draw logical conclusions. One famous example followed the death of a Union General, John Sedgwick, in the American Civil War. He chided his men for cowering from Confederate snipers, firing at 1000yds, hubristically declaring "one couldn't hit an elephant at that range", before he was killed instantly by a bullet through his head. The explanation was found when the offending bullet was removed and was discovered to be hexagonal in shape. This confirmed that it could only have been fired from a British Whitworth rifle, a weapon capable of exceptional accuracy for its day and sold in numbers to the Confederate side.

Another early example includes a "cloth patch" which had been wrapped round a musket ball and recovered from the wound of a murder victim (wrapping a ball in greased cloth patch improved accuracy). The “cloth patch” had been torn from a suspect’s handkerchief, thereby linking him conclusively to the murder.

The first documented forensic ballistics case in the UK was in 1835. Henry Goddard, a Metropolitan Police officer, was investigating a murder where the victim had been shot with a lead ball projectile. Upon inspection of the recovered projectile, Goddard noticed a casting mark left by the mould which had formed the lead “bullet”. A suspect was identified and a bullet mould recovered from his home. Test samples from the suspect’s mould compared with the casting marks on the recovered projectile allowed Goddard to confirm that the fatal bullet had been produced from the suspect’s mould. He was convicted of the murder.

In the UK, what we would now recognise as forensic ballistics began in the 1920s when two pioneers, Robert Churchill and Major Gerald Burrard, started looking at the examination of bullets and cartridge cases to see if they could be linked to specific weapons. One of the first cases in the UK to use forensic ballistics was the infamous murder of PC William Gutteridge in 1927 (PC Gutteridge had been shot through the eyes, possibly because of superstitious beliefs). Robert Churchill was able swiftly to match the bullets to a gun found at a suspect’s house. Although the comparison microscopes were crude by today’s standards, the fundamental principles of comparison microscopy were established by these early pioneers. After WW2, the Forensic Science Service consolidated all firearms examination in England and Wales, and was largely responsible for setting the foundations for modern forensic ballistics examinations in the UK. Nevertheless, although technology has had an impact on the work, enabling, for example, rapid searching of bullets and cartridge cases, most forensic ballistic work remains little different from that which Churchill and Burrard practised nearly 100 years ago.

2. Ballistics

2.1 Firearms Types and Operation

There are many different types of firearms, but only certain types are commonly used in crime in the UK. At the time of publication, handguns and sawn-off shotguns predominate, with over 90% of serious armed crime involving these weapon types. This section thus concentrates on them, although it does also refer to guns such as sub-machine guns and assault rifles, which, whilst much less common, are sometimes used by criminals.

Self-loading pistols (Figure 1)

Most self-loading pistols consist of a frame or receiver with a reciprocating slide. Sometimes the barrel is fixed to the receiver, sometimes a separate part which moves during the firing cycle. Generally, self-loading pistols operate using a spring-operated box magazine, the bulk of which is fitted into the handle of the pistol. They fire one cartridge for each pull of the trigger, with fired cartridge cases being ejected from the weapon.

Figure 1. A self-loading pistol

Self-loading pistol operation (Figure 2)

During normal operation, a magazine is filled with a number of cartridges and is inserted into the magazine well. The pistol's slide is pulled to the rear and released; as it travels forward, under the force of a spring, the top cartridge is stripped from the magazine and fed into the chamber. The pistol is now cocked and loaded. From this point, assuming any safety catch is set to the fire position, pressure on the trigger will fire the weapon.

On firing, recoil forces cause the cartridge case to be thrust back against the slide, which is pushed to the rear allowing the empty, fired, cartridge case to be ejected from the weapon. As the slide travels forward again, propelled by a mainspring, it strips the top cartridge from the magazine and feeds it into the chamber. The hammer or striker remains cocked and the trigger must be released and pulled again before the newly chambered cartridge can be fired.

This type of pistol will fire a single cartridge for each pull of the trigger. Once the magazine has been emptied, the pistol's slide will be held at the rear, demonstrating to the user that the weapon is empty.

Figure 2. Self-loading (semi-automatic) pistol operation cycle:

A. Gun at rest with loaded magazine containing live cartridges.

B. Slide is pulled rearwards and released forward, chambering a live cartridge from the magazine and cocking the hammer.

C. The trigger is pulled; hammer strikes the firing pin which in turn detonates the live cartridge forcing the bullet down the barrel.

D. Recoil forces slide rearwards, extracting the spent casing and on the forward movement reload a new live cartridge from the magazine.

Revolvers (Figure 3)

Revolvers derive their name from the revolving cylinder, which holds the cartridges. The cylindrical, rotating part of a revolver contains separate chambers revolving round a central axis to align the individual chambers with the rear of the barrel for firing. Cylinders typically hold six cartridges, but there are exceptions.

Figure 3. A revolver

Cartridge firing revolvers generally come in one of three forms:

- Solid frame revolvers with the cylinder held in the frame, fixed behind the barrel. These are normally loaded via a slot in the rear of the frame known as a gate. These are known as gate-loading revolvers (Figure 4).

Figure 4. Gate loading revolver

- Hinge frame revolvers (Figure 5), where the frame is hinged usually at the front of the frame below the barrel. Cartridges are loaded into the weapon's chambers after the frame is broken open.

Figure 5. Hinge frame revolver

- Solid frame revolvers, with a swing out cylinder (Figure 6). The cylinder is mounted on an arm, the crane, which normally swings out to the left-hand side of the weapon.

Figure 6. Swing-out cylinder revolver

Revolver operation

Revolvers are designed to be fired in single or in double action mode.

In single action, the hammer is manually cocked. As the hammer is raised, the revolver's cylinder rotates automatically to bring the next cartridge to be fired beneath the hammer. Once cocked, pressure on the trigger fires the weapon.

In double action, as the trigger is pulled, the cylinder rotates automatically and the hammer is raised almost to its rearmost position, from which point it discharges the weapon.

The fired cartridge cases remain within the weapon, unless removed by the firer.

Shotguns (Figure 7)

Shotgun design and operation

Shotgun types: There are four main types of shotgun, single-barrelled weapons, double-barrelled weapons, pump action weapons and self-loading weapons.

Figure 7. Typical double-barrelled shotgun (top) and a shortened or “sawn-off” single barrel shotgun (bottom)

Double-barrelled & Single barrelled weapons

Most double-barrelled shotguns have a so-called break action, the weapon hinging just forward of the firing mechanism, exposing the rear of the barrels. In side-by-side weapons, the barrels are laid alongside each other; in ‘over and under’ shotguns, the barrels are one above the other.

Some double-barrelled shotguns have one trigger, some two. Conventionally in double-trigger guns, the front trigger fires the right-hand side or lower barrel. On single-trigger guns, the order of firing is set; in others, the order is determined by the firer, using a switch on the safety catch. The selected barrel is fired first; pulling the trigger again will fire the other barrel.

Some weapons have exposed hammers and others have internal hammers. Weapons fitted with a hammer must be manually cocked before the weapon will discharge. Weapons with external hammers are cocked automatically as the weapon is opened to be loaded.

Once a cartridge is loaded into the chamber and the weapon closed and cocked and any safety catch set to the fire position, pulling the trigger will fire the weapon.

Single-barrelled weapons are identical in operation but have only one barrel and one trigger.

Pump-action and Self-loading weapons

Both these types of weapon have a single barrel; they are magazine-fed, the magazine usually a tube beneath the barrel. Cartridges are fed into the magazine through a port on the underside of the weapon. Cartridges are chambered from the magazine either by operation of a pump handle (pump-action) or by manual operation of a bolt (self-loading). Once loaded, pulling the trigger will fire any chambered cartridge.

A pump-action weapon is reloaded by operating the pump-handle, the fired cartridge case ejected from the chamber and a fresh cartridge from the magazine loaded. Releasing and pulling the trigger will fire this chambered cartridge. A self-loading weapon ejects the fired cartridge case automatically from the chamber and feeds a fresh cartridge from the magazine into the chamber; again, pulling the trigger will fire the freshly chambered cartridge.

Sub-machine guns and assault rifles (Figure 8)

Neither type of weapon is commonly seen in gun crime in the UK. The main difference between the two is that the sub-machine gun uses pistol ammunition and the assault rifle an intermediate cartridge, i.e. one lower powered than a normal rifle cartridge. Both weapon types are generally “selective-fire” weapons in that they can fire single shots, each requiring a separate pull on the trigger for each shot, or “full-auto”, where the gun will continue to discharge for as long as the trigger is depressed and there is ammunition in the magazine.

Figure 8. The AK47 assault rifle and MAC-10 sub-machine gun,
both capable of fully automatic fire

2.2 Ammunition

Metallic, centrefire, bulleted cartridge construction (Figure 9)

Conventional metallic, centrefire, bulleted cartridges consist of four constituent parts: a cartridge case, propellant powder, a primer and a projectile (Figures 10 and 11). The primer, the ignition system of the cartridge, sits in the base of the cartridge case, the propellant is housed inside the cartridge case and the projectile sits in the cartridge case mouth. In common parlance, people often refer to a round of ammunition as a “bullet” whereas technically “bullet” refers only to the projectile.

NB. In this Primer, “bullet” and “projectile” should be regarded as interchangeable.

Figure 9. Metallic bulleted cartridges in various calibres

Figure 10. The components of a bulleted cartridge

On firing a bulleted cartridge, the cartridge case expands slightly, forming a tight gas seal at the rear of the barrel, helping to maintain sufficient pressure to propel the bullet down the barrel at optimum velocity.

Production of ammunition

Conventional centrefire cartridges can be produced in one of two ways:

1) Factory made. The cartridges are assembled in a factory.

2) Hand-loaded/reloaded. The spent primer is removed from a previously fired cartridge case. A replacement live primer is added to this cartridge case, with a measured quantity of propellant and a projectile, to form a new round of ammunition. Hand-loaded/reloaded cartridges are assembled somewhere other than in a conventional factory, generally at home. The constituent parts of the cartridges can be bought separately and assembled to form whole rounds of ammunition. (This should not be confused with the term ‘reloading’, which can apply to changing magazines or inserting cartridges into a gun after discharge.)

Bullet styles

Bullets for use in cartridges come in a number of styles categorised by shape, material and composition. Most bullets are made of lead or have lead in their composition. Some bullets have harder metal jackets, usually copper alloy or copper-plated steel. The jackets of bullets may cover all (full-metal jacket) or part (semi-jacketed) of the bullet. In the former, the base of the bullet is exposed, showing the (lead) core. In the latter, the base of the bullet is covered, exposing either a small amount of lead at the nose (soft-point) or a hole or depression (hollow-point). These are designed to expand on impact.

Figure 11. Cartridge cases, bullets, propellant and primers

How a centrefire cartridge works (Figure 12)

In a centrefire metallic cartridge, the firing-pin strikes the primer in the centre of the base of the cartridge. The priming composition explodes and a jet of flame passes through the flash-hole in the cartridge case and ignites the propellant powder within the body of the cartridge case. The propellant powder burns, producing a large volume of gas. This expanding gas pushes the bullet out of the cartridge case and down the barrel of the firearm.

Figure 12. Centrefire primer detonation

How a rimfire cartridge works (Figure 13)

Rimfire cartridges are made from a thin sheet of metal folded to form the shape of a cartridge. The priming composition sits in the base of the cartridge case and, during manufacture, is spun into the rim.

Figure 13. Rimfire primer detonation

Rimfire cartridges sit in the weapon's chamber, rims against the back. The firing-pin strikes the rim at the base of the cartridge, and crushes the rim against the rear of the chamber so crushing the priming composition between the fold of metal at the base of the cartridge. 0.22 is an example of a rimfire cartridge and one of the most common calibres worldwide. See Glossary and Chapter 2.3 for further discussion on calibre.

Propellant powder (Figure 14)

Propellant powder comes in a variety of forms and chemical compositions depending upon the purpose for which it is intended. (This is dealt with in more detail in the section on Gunshot Residue).

Propellant powder burns rather than explodes, but is burned very rapidly when confined in a cartridge case in the barrel of a weapon. The rate of burning increases as pressure increases. The pressure in the barrel drops when the projectiles exit the muzzle (the front end of the barrel).

Figure 14. Smokeless propellant powder

Shotgun cartridge construction (Figures 15 and 16)

Conventional shotgun cartridges consist of five constituent parts: a cartridge case, propellant, primer, wad and a quantity of shot pellets or a single projectile.

Whilst generally made of lead alloy, shotgun pellets may be made of other materials including steel, bismuth and tungsten. Generally, shot are spherical.

Figure 15. Shotgun cartridges,
common 12 gauge and .410 calibre examples

Cartridge case

Shotgun cartridge cases consist of a plastic or cardboard tube, the rear of which is covered with a metal cap-like structure known as the head. Whilst generally made of steel, it is often plated with brass. This portion of the cartridge case houses the primer assembly and is generally marked with a headstamp. The headstamp usually identifies the calibre of the cartridge case and often the manufacturing company. The side of the cartridge case often bears markings from the company which loaded the cartridge or might be marked with a retailer's name as well as additional information such as shot size.

The cartridge case contains the remaining components of the cartridge.

Figure 16. A shotgun cartridge:
A = lead shot, B = plastic wad, C = propellant, D = plastic cartridge case
& E = metallic base incorporating a primer

Wads (Figure 17)

Wads are internal components of shotgun cartridges. Their purpose is to seal the gases produced by the burning propellant in the barrel of the shotgun and to protect the shot. They can be made from various substances including plastic, fibre, cardboard and combinations thereof.

Some plastic wads include a cup-shaped section to hold the shot pellets; this is made up of a number of petals or fingers. Conventional shotgun cartridges can contain different quantities of shot depending upon the use for which they are intended. For example, a 12-gauge cartridge will normally contain between 21 and 42 grams (g) of shot, with between 27g and 36g being most common.

Shot pellet sizes

Shot pellets for use with shotgun cartridges are graded according to size. In the United Kingdom, the larger the number, the smaller the size of the shot pellets. For example, a number 1 size shot will be approximately 3.6mm diameter, whereas a number 5 will be approximately 2.8mm diameter. Number 5, 6 & 7 size shot are commonly used for hunting small game and for clay pigeon shooting, and, because of their availability, are also frequently used in crime.

Figure 17. Fibre wadding, a plastic wad and lead shot

Blank and tear gas weapons

Blank and tear gas cartridge construction (Figures 18 and 19)

Modern blank cartridges for self-loading pistols are similar in design to bulleted cartridges with the exception that they lack a projectile. Most have a (green) coloured plastic closure at the case-mouth. The front of the cartridge case is rolled over the plastic closure to hold it in place.

Fig18. The components of a blank cartridge

Tear gas cartridges are essentially identical with the exception that they contain a small amount of tear gas material in the form of a finely divided crystalline solid. Such cartridges have coloured plastic closures, the colour indicating the type of tear gas chemical present. Weapons designed to fire blanks and irritant gas cartridges are sold freely on the continent and often referred to as gas/alarm pistols. The pistol discharges the irritant tear gas a short distance from the muzzle, theoretically deterring an attacker. In the UK they are prohibited weapons and are easily capable of conversion to discharge a missile. Certain types of UK blank-firing weapons, incapable of conversion or discharging tear gas, are not prohibited by statute.

Figure 19. Blank & tear gas cartridges often show coloured plastic closures,

typically green (blank) and red (tear gas)

Tear gas firing (or gas/alarm) self-loading pistol operation

Normally, tear gas firing self-loading pistols operate in an identical way to normal self-loading pistols, except no projectile (only tear gas) is expelled from the barrel. In addition, many of these pistols have a threaded muzzle to enable them to be fitted with a flare launcher, the flare being launched by using a standard blank cartridge.

2.3 Calibre

True calibre is a measure of the internal bore of a weapon, but in common usage, calibre refers to the type of cartridge a gun is designed to fire. An example of a common pistol calibre is the 9mm Parabellum, the most common pistol calibre in the world. Confusingly, there are often several different designations for the same calibre, and so 9mm Parabellum is also called 9mm Luger, 9mmP, 9mm NATO or 9x19mm. In addition, there are other 9mm calibres such as 9mm Makarov and 9mm Short. These cannot be discharged in a 9mm Parabellum pistol nor are they compatible with one another. For this reason, forensic scientists should always be specific in their statements and will normally comment on the compatibility between any weapon and ammunition examined.

Calibres with metric dimensions are usually European in origin whilst those with imperial dimensions are usually North American or British in origin. Obsolete calibres are calibres for which ammunition is no longer commercially available, and weapons chambered in these calibres are often regarded as antiques under UK law.

2.4 Internal Ballistics

The subject of Internal Ballistics covers the time from when the primer is struck until the projectile exits the barrel.

When the trigger is pulled, the firing pin will strike the primer at the base of the cartridge. This causes a shower of sparks to ignite the propellant powder in the cartridge case. The propellant powder burns at a very high rate, creating a large volume of gas and a substantial increase in pressure. The pressure is contained by the breech block at the rear of the cartridge and the barrel surrounding the cartridge, so that the pressure will act on the projectile (or the wad in a shotgun) driving it down the barrel.

The rate at which the propellant burns is calculated to ensure that the pressure continues to rise so that the projectile travels down the barrel. One might expect, therefore, that the powder in a pistol cartridge would burn more rapidly than the powder in a rifle cartridge, the slower burning of the rifle cartridge ensuring constant acceleration of the projectile down the longer barrel. This is the case, and also explains why the same projectile fired from the same cartridge but from a weapon with a shorter barrel will produce a lower velocity than from a long barrel. Similarly, projectiles from a 'sawn-off' shotgun or rifle will produce lower velocities.

2.5 External Ballistics

The subject of external ballistics deals with the behaviour of the projectile after its exit from the barrel, during its flight and then when it makes contact with a target – this is the trajectory. Many factors combine to influence the trajectory of the projectile.

When in-flight, the main forces acting on the projectile are gravity and air resistance (which can take the form of both drag and wind deflection). When looking at small arms external ballistics, gravity imparts a downward acceleration on the projectile, causing it to drop from the line of sight. Drag or air resistance, decelerates the projectile with a force proportional to the square of the velocity. Wind makes the projectile deviate from its trajectory.

As a projectile drops due to gravity, the projectile follows a parabolic trajectory. To ensure the projectile has an impact on a distant target, the barrel must be inclined to a positive elevation relative to the target line. This is known as sighting the weapon and explains why a weapon has to be sighted at different ranges. To give a practical example, a projectile fired from a rifle sighted to hit a target at 150 metres might also strike the point of aim at 50 metres but will shoot high at 100 metres and low at 200 metres (Figure 20).

Figure 20.
A = an unsighted rifle will miss the aim point at 150 metres due to the effects of gravity and deceleration on the projectile's trajectory
B = a sighted rifle will compensate for these effects with a parabolic trajectory and hit the aim point at the 150 metre mark

Projectiles discharged from a rifled barrel are spin-stabilised, the spin created by rifling as the projectile passes through the barrel. The spin gives the projectile gyroscopic stability, preventing it from tumbling in flight. Without this spin being imparted to the projectile, it quickly becomes unstable, and accurate shooting is impossible.

Ballistic tables predict the path of a bullet considering the many external factors above. If the ballistic coefficient (BC) of a projectile is known – it combines the air resistance of the bullet shape (the drag coefficient) and its sectional density (a function of mass and bullet diameter) - all parameters relating to ballistic flight can be calculated. These are sometimes used by forensic scientists to determine, for example, the maximum distance a projectile fired from a particular weapon could travel. It should be noted, however, that use of this type of information is rare, as most criminal shootings take place at very close range, rarely exceeding a few metres.

2.6 Terminal ballistics

Terminal ballistics includes the study of wound ballistics, and generally relate to the behaviour and effects of a projectile when it has an impact on a target and transfers its energy thereto. Bullet design and the velocity of impact largely determine how effective the contact is. "Terminal ballistics" covers the impact of any projectile striking any target, but often concentrates on the effects of small arms ammunition on a live target, human or animal, and the ability of the projectile to incapacitate or kill. Significant factors are bullet weight, composition, velocity, and shape.

Projectiles are designed either for maximum accuracy or for penetration of a target whilst avoiding over-penetration. They thus cause maximum damage to the intended target, but minimise the risk of peripheral unintended damage.

Frangible bullets are designed to disintegrate when they impact a target, particularly a hard target. This reduces the risk of over-penetration and contact with unintended targets. They are often used for training or for law enforcement in densely populated areas.

Expanding bullets, such as a hollow-point or soft-point bullets are designed to expand or fragment shortly after impact. This causes a rapid transfer of the bullet's energy thereby increasing tissue disruption, speeding incapacitation and also the likelihood of death. It also reduces the chance of over penetration (where the projectile leaves the intended target and may accidentally make contact with a secondary target).

Armour-piercing bullets are designed to defeat hard targets; they will have a mild steel or hardened steel core and will be designed to stay intact on impact to aid penetration power. Hard targets include body armour and armour used to protect vehicles.

3. Scene Interpretation

The assessment and interpretation of a firearms crime/discharge scene is a very important part of the role of a firearms forensic scientist. Here we can determine a number of factors including:

a. Number of weapons/type of weapon/firearm utilised
b. Number of discharges
c. Position of shooter or firing point
d. Angle of discharge
e. Range of fire.

It is important from a police investigative perspective that the scientist can provide this type of information as quickly as possible. The recording and recovery of any ballistic item is of extreme importance. First, it can provide an accurate interpretation of the crime scene, a major benefit for expert evidence testimony in a court of law; second, if the ballistic items are recovered in a controlled manner, there is then maximum potential for evidence recovery from them later in the examination process at the forensic laboratory. This evidence can be DNA or fingerprints (or both), for example. It certainly is a major benefit if those at the scene of a shooting are highly experienced in the field of forensic firearms/ballistics, as this ensures an accurate interpretation and effective and efficient recovery of potential exhibits.

3.1 Ricochet

This is not a common occurrence in criminal shootings, but the firearms expert will assess the scene for yielding, semi yielding or non-yielding surfaces, if it is suspected that the projectile has not followed a normal trajectory. In such cases, the bullet/projectile is likely to bear specific damage due to the effects of having ricocheted off a particular surface.

- A yielding surface could be sand or some types of soft wood
- A semi-yielding surface could include some types of metal or harder wood and
- A non-yielding surface could be steel or other hard metal.

A major factor is the elasticity of a surface and the expert will determine how this might cause a bullet/projectile to act after striking such a surface.

3.2 Trajectory

Determining the trajectory of a bullet will help the scientist form a conclusion as to the location from where the shot was discharged. This can be done with the use of modern equipment such as lasers, but traditional methods, such as inserting steel rods through entry/exit holes, are still used, particularly in post-mortem examinations of victims of shooting.

3.3 Damage and range interpretation

An examination of the damage caused, can often lead to a determination of the type of bullet, calibre etc. It can also be used to look at the range at which a shot has been discharged, particularly when shotguns are used. This is because the pattern of the shot will increase with range. Typically, the shot pattern spreads approximately 2.5cm for every metre it travels from the muzzle, but this will vary with different guns and cartridges. It is a popular myth that a sawn-off shotgun produces greatly enlarged patterns at any given range, but in reality, the patterns produced from most sawn-off shotguns are little different from those produced from full-length weapons.

3.4 Wound interpretation

This aspect is generally considered by a forensic pathologist. Nevertheless, ideally, a forensic pathologist working in conjunction with the firearms expert will be more likely to produce an accurate and reliable interpretation. Unfortunately, many myths surround how entry and exit wounds are differentiated, an example being that exit wounds are always larger than entry wounds. In fact, many factors affect the size and morphology of these wounds and only with considerable experience can an expert determine entry and exit wounds, bullet calibre, distance determination and direction of fire.

4. Microscopy

4. 1 Introduction

Microscopic tool markings found on fired ballistic material, such as cartridge cases and bullets are examined using a comparison microscope. This particular technique of examining ballistic tool markings is generically referred to as “microscopy”, and forms part of established forensic science practice used by ballistic examiners around the world.

The foundation principles of microscopy used by ballistic examiners were formally established in 1969 by the Association of Firearm and Tool-mark Examiners (AFTE), based in the United States. The AFTE “Theory of Identification” underpins the basis of microscopy as it is applied by ballistic examiners and is comprised of three main principles:

1. An expert ballistic examiner may form the opinion that two ballistic samples match if there is “sufficient agreement” of microscopic tool markings.

2. That “sufficient agreement” is related to the significant duplication of random tool markings. These random tool markings contain “individual characteristics” in the form of peaks, ridges and furrows within surface contour markings. A match is established when sufficient corresponding “individual characteristic” markings are found between two sample sets. Agreement is considered sufficient when it exceeds the best known “non-match” of markings known to the expert examiner that originate from different tools; therefore, making the likelihood of a different tool having been used a “practical impossibility”.

3. That “sufficient agreement” of tool markings is subjective and the interpretation is based only on an examiner’s training and experience.

In addition to this, expert ballistic examiners also generally use the following range of conclusions upon completing a microscopic comparison,

- Conclusive - The items were marked by the same weapon.

- There were indications that the samples were marked by the same weapon, but there is insufficient detail present to determine conclusively.

- The comparison was inconclusive; it was not possible to determine whether the items had been marked by the same weapon.

- There were indications that the samples had been marked by different weapons, but there is insufficient detail present to make a conclusive determination.

- Elimination - The items were marked by different weapons.

It should be made clear that there has been much criticism in recent years of the basis on which ballistics experts reach their conclusions and in particular the definition of ‘sufficient agreement’ and the assertion of a ‘practical impossibility’ based only on the examiner’s training and experience. Much of the criticism has been in the USA, and has focused on a lack of peer reviewed scientific papers relating to the subject, as well as an absence of error rates in such a subjective analysis.

In the UK, all significant conclusions drawn must be peer reviewed by at least one additional expert examiner. The peer review process must be conducted independently and objectively to ensure a non-biased result. If different conclusions are reached by expert examiners, or differing levels of agreement found between expert examiners, this will be disclosed to the court via the evidential statement provided by the expert examiner.

All forensic science providers in the UK who are presenting firearms and firearms discharge residue evidence in court should be accredited to the International Standard ISO 17025-2017. As part of achieving this standard, the forensic science providers would have to satisfy the UK Accreditation Service that their microscopic examinations are part of a scientifically valid process. This would include;

- the production of error rates associated with the conclusions derived from the comparison of ballistic material.
- evidence to support the assertion that certain markings produced by firearms on bullets and cartridge cases could be attributed to an individual firearm.

Error rates in microscopy at the NABIS and NABIS-affiliated laboratories are determined from over ten years of competency testing of ballistic experts. This has involved over 700 blind competency tests with around 1,000 potential links. The error rate for false negatives (links not identified) is 2.1% and the error rate for false positives (links identified that are not links) is 0.7%. The latter figure is of most concern. With the independent peer review system, the error rate for false positives falls to approximately 0.005%, or one in 20,000.

Scientific research to objectively underpin the assertion that a particular bullet or cartridge case could be attributed to an individual firearm is also slowly progressing.

4.2 Identification of weapons

When a firearm is discharged, marks are left on cartridge cases and bullets. These have been produced by parts of the firearm as it has come into contact with the surface of the cartridge case or bullet.

Ballistic material such as fired cartridge cases and bullets are recovered from a crime scene and submitted to a forensic firearms laboratory (Figure 21) . The firearms examiner will view the marks on the fired items under a comparison microscope.

Examination of certain marks on fired cartridge cases and bullets recovered from a crime can initially aid the identification of the type of weapon from which the ammunition was fired. These marks might be

(a) Class characteristics- a series of “family” resemblances which might be present in weapons of the same make and model. These marks are a result of design factors of the gun;

(b) Sub Class Characteristics: where the features introduced during the manufacturing process can change over time and usage; and

(c) Unique characteristics - randomly occurring features created at the time of manufacture and during use and abuse of the tool.

Figure 21. Fired ballistic material commonly recovered from crime scenes

Cartridge Cases

The primary marks left on the fired cartridge case are made by the firing pin, the breech face of the gun, the ejector and the extractor.

Figure 22. Microscopic comparision of two fired cartridge cases showing impressed firing pin and breech face markings

Bullets

The marks on the fired bullet are made by the rifling on the inside of the barrel. The rifling marks will be either a left (L) or right (R) twist, and consist of the number of lands/grooves, e.g. 6L, 4R. The width of the lands and grooves can also be taken into account to contribute to identification of make and model.

Figure 23. Microscopic comparision of two fired bullets showing striated rifling detail

4.3 Comparison of fired items (Figures 22 and 23)

Under a comparison microscope, further examination can reveal fine detail present on the cartridge cases and bullets. These marks are known as individual characteristics, which are reproducible and unique to the gun which produced them. They are produced by random imperfections or irregularities of a tool's surface.

Individual characteristics are often present within the firing pin impression, the breech face marks, ejector mark etc. on cartridge cases, and within the rifling marks on bullets. If the bullet were fired in a barrel with no rifling (smoothbore), individual characteristics might also be present on the marks left on the bullet from the internal surface of the barrel.

It is these individual characteristics which allow forensic firearms examiners to form an opinion that items were fired from the same gun.

For instance, a fired cartridge case from incident A can be compared to a fired cartridge case from incident B. The examiner will examine both items together under a comparison microscope for similarity in striations etc. If sufficient fine detail is present in agreement, the examiner will be able to state that both cartridge cases were fired by the same gun. This implies that the same gun was used in both incidents.

4.4 Linking Ballistic Material to a Recovered Weapon

When a firearm is recovered, it can be submitted to a forensic firearms laboratory and test-fired. Using a comparison microscope, the test-fired cartridge cases and bullets can be compared to fired items recovered from outstanding crimes. The examiner can form an opinion as to whether the items were fired by the same gun. If sufficient fine detail is present, the examiner can state that a fired item was fired by the recovered gun.

4.5 The Integrated Ballistic Identification System (IBIS) Figure 24

Ballistic examiners often use an electronic automated searching system called IBIS (Integrated Ballistic Identification System), which allows "virtual" analysis of ballistic samples held across different laboratories. It is a database of digital images which can be searched using correlation software. The software will rank potential matches for the expert to review on screen and offers quick time analysis. Within the UK, IBIS is installed at laboratories in London, Manchester, Birmingham, Glasgow and Belfast, providing complete national coverage.

IBIS is comprised of three main components:

BrassTRAX HD3D acquisition unit

This unit allows the examiner to load physical samples of fired cartridge cases. The unit captures 3DHD digital images of the firing-pin impressions, ejector markings and head-stamp details on fired cartridge cases.

BulletTRAX HD3D acquisition unit

This unit allows the examiner to load physical samples of fired bullets. The unit captures 3DHD digital images of the rifling impressions on fired bullets.

MatchPoint Plus analysis station

This station allows the examiner to review images of potential matches. Advanced computer software provides an accurate correlation list of potential matches, ranked in order of probability, and a “virtual microscope” to view ballistic image comparisons.

Once physical ballistic samples have been loaded onto the BrassTRAX and/or BulletTRAX acquisition units, the captured digital images are submitted to a correlation server where they are automatically analysed using mathematical algorithms which return results to the MatchPoint analysis station. The expert ballistic examiner will review all relevant images on screen to determine whether there is any link. All potential matches highlighted by IBIS are further manually checked on a traditional comparison microscope.

It is also worthy of note that the UK based IBIS has the facility to search against servers of other IBIS member countries, offering an international searching ability to ballistic examiners.

Figure 24. IBIS 3DHD imagery of two fired cartridge cases

5. Mechanical Condition

A suspect firearm can be examined to determine whether it is in normal working order and/or could be discharged accidentally. The expression "accidental discharge" could mean the gun has been fired due to:

- an inappropriately low trigger pull
- the failure of a safety device
- an unintentional discharge due either to pressure inadvertently applied to the trigger , or
- some other failure of the gun due to poor condition.

5.1 Trigger Pressures

There are two general types of firearm mechanism or 'lock':

- a hammer which rotates round an axis, for example the external hammer in a revolver or the internal tumbler in a shotgun or
- a striker or bolt which moves longitudinally, for example the striker in a pistol, the cocking knob in a bolt-action rifle, or the bolt in a sub-machine gun.

In each case, the hammer or striker/bolt is powered by a spring and is held in the cocked position by an internal component called the sear. The sear engages either in a notch called the bent or sometimes, in the case of a striker, behind a protruding lug. The trigger is a lever which lifts the sear out of engagement with the bent allowing the hammer or striker/bolt to be driven forward under spring tension and to detonate the cartridge primer via the firing pin.

There are many variations on this general principle, but all rely on the sear being dragged out of engagement from the bent, i.e. on the separation by motion of two interacting metal surfaces. The science of interacting surfaces in relative motion, including the study of friction, lubrication and wear, is known as tribology.

Trigger pull is the force applied to the trigger to cause sear release. Trigger pull is traditionally described in units of weight (pounds or kilograms) and measured by hanging calibrated weights on the trigger to determine whether a given weight will fire the gun or whether the hammer will remain held by the sear. Spring gauges or digital force gauges can give a crude indication of trigger pull.

The most significant factor affecting trigger pull is the spring pressure on the hammer or striker/bolt. Some sears might also be under tension from a sear spring. Other factors relate to the engagement of the sear with the bent, i.e. the shape and profile of both sear and bent, the surface area of contact, and the friction from rough or polished surfaces. Variable factors include the presence of rust, dirt or oil, and surface temperature.

Consideration might be given to the angle at which the gun is held. In normal use, the operator's finger will tend to apply pressure to the trigger in a direction slightly upward relative to the longitudinal axis of the gun, whilst the very minimum weight necessary to fire the weapon might be achieved at the tip of a curved trigger applied in some other direction. Clearly, there is much variation here depending on weapon type and design.

The trigger pull might be assessed as normal for that particular type of firearm, or dangerously light or excessively heavy. For example, a sporting shotgun will have a normal trigger pull of 3½ to 5lb, a military rifle 6 to 8lb etc. The trigger pull of a suspect weapon might be compared with others of the same make held in a reference collection, or with values collated in databases or published sources. There is a subjective element to interpreting whether a trigger pull might be regarded as normal. For example, a relatively light trigger pull might be acceptable on a controlled firing range but not in the field. A trigger pull of less than 1lb is dangerously light.

5.2 Safety devices, external and internal (Figure 25)

Many weapons are fitted with an external safety catch. The exceptions include shotguns with external hammers, almost all revolvers and many cheap air weapons.

Most safety catches are applied manually at some stage during the normal loading and firing procedure, but some weapons, including certain shotguns and air rifles, have an automatic safety which sets when the barrels are opened. The location of a safety catch will depend on the type of gun. Typical examples include on the frame or slide of a self-loading pistol, behind the opening lever of a shotgun, on the receiver or bolt of a rifle, or incorporated within, or close to, a trigger guard. There is much variation.

The position of a safety catch might, depending on design, be indicated visually by a letter S for 'safe' or 'on' and F for 'fire' or 'off', or by a red dot or band obscured when the safety catch is in the 'safe' position but revealed in 'fire' position. There is much variation, but the safety catch will be positioned so that it can be readily moved to 'off' by the operator's thumb.

Most safety catches are connected to a mechanism which physically blocks movement of the trigger thereby preventing discharge. For a given suspect weapon, the normal operation of the safety catch can be tested, and the condition of its components assessed.

Certain types of firearm might have internal safety features designed to prevent the gun from discharging except by pressing the trigger. These include, but are not limited to, a rebound safety, a transfer bar, a disconnector and a firing pin safety. In general, these passive safety mechanisms prevent a gun discharging if it is dropped to the ground, or if the normal loading and firing procedure is not followed. There is much variation depending upon weapon type, and even make and model.

Figure 25. Two examples of safety catches, one with symbols and the other with text to identify “safe” and “fire” positions

5.3 Unintentional discharge

‘Unintentional discharge’ is generally taken to mean:

a) due to a faulty trigger mechanism or safety device or a broken, worn or missing part, the gun has been discharged other than by pressing the trigger in the normal manner
b) pressure was applied to the trigger by some means other than the operator pressing the trigger in the normal manner (perhaps caught up in clothing or struck by some other object) or

c) the trigger was pressed by the operator but not deliberately or consciously (perhaps in the heat of the moment, or by surprise).

A suspect weapon can, in light of one of the above allegations, be subjected to drop tests and jarring tests. Drop (or “bumping”) tests involve dropping the gun under controlled conditions onto known surfaces in various orientations and from various heights. Such tests can demonstrate whether the sear is released from the bent without the trigger being pressed, or whether the firing pin is driven onto the cartridge primer due to inertia. Jarring tests involve striking the gun at various points and in various directions.

In general, a gun with a light trigger pull is more susceptible to sear release due to bumping or jarring. Drop tests and jarring tests are best designed to reproduce the effects of any scenario proposed by the prosecution or defence. A different approach might be taken if the allegation is of a shot fired during a struggle compared with, say, the gun being dropped to the ground. Care will be taken since drop and jarring tests have the potential irreparably to change the mechanical condition of the gun.

6. Gunshot Residue

6.1 What is gunshot residue?

Gunshot residue (generally referred to as GSR, but which may also be called cartridge discharge residue (CDR) or firearm discharge residue (FDR), is a mixture of chemical compounds produced as a result of a series of high-pressure chemical reactions which are intended to force the projectile down the barrel of the firearm. It is the collective name of the complex mixture of organic and inorganic particles and compounds originating from the firearm, the ammunition and from the combustion products which are produced during the discharge of a firearm. GSR consists of particles arising from ammunition primer, burnt and unburnt propellant powder, metals from the projectile (firearm ammunition), grease, lubricants, and metals from the gun barrel (firearm) combustion products, including smoke. Inorganic compounds such as nitrates, nitrites and metallic particles, originate from the primer and propellant, as well as the cartridge case, projectile jacket and its core, and from the gun barrel. Organic compounds mainly originate from propellant powders, firearm lubricants, some transformation products and hydrocarbons.

Gunshot residue escapes through weapon openings and can subsequently be deposited on surfaces in the vicinity of the fired weapon. The majority of GSR will generally travel approximately 3-4 metres forward, 1 metre either side and 1 metre behind the shooter. Anyone within this area might acquire GSR on their person. Gunshot residue might be deposited onto the skin, hair or clothing of the person who has discharged the firearm, on the entrance to (and inside) the wound of a victim, or on other target materials at the scene. A recently discharged firearm will also retain GSR on its inner and outer surfaces. This GSR will persist indefinitely until physically removed, for example by cleaning.

The potential for GSR to establish a link between shooter, firearm, victim, and/or crime scene requires careful interpretation of the gunshot residue evidence. It is important to understand that due to the complexity of the firing process, and the parameters involved in the creation of gunshot residue, the number of GSR particles produced and their composition will vary from shot to shot. Additional complexity is added by the wide range of firearms and ammunition available.

The role of the GSR expert in the UK is to assess and evaluate any GSR evidence in firearms-related cases. The presence and/or absence of GSR can aid the reconstruction of shooting incidents: to estimate firing distances; to identify bullet holes and ricochet marks; and to determine whether or not an individual has discharged a firearm. It has also been used to distinguish entry and exit wounds; to differentiate homicide from suicide; and to determine the time since the most recent discharge.

Formation

GSR can be categorised into 2 main types: Inorganic GSR (IGSR), also known as Primer GSR, and Organic GSR (OGSR). As the firing pin of the weapon strikes the primer cap (Figure 10), the primer mixture is ignited, which in turn ignites the propellant. This creates an environment of rapid temperature and pressure increases within the cartridge resulting in the projectile being propelled from the firearm barrel. The ignition of the primer mixture and increase in temperature result in vaporisation of the primer elements. The extreme temperature and pressure are followed by rapid cooling when combustion materials escape from weapon openings resulting in particle formation of IGSR.

OGSR is not formed by the firing process. It mainly originates from propellant powders, firearm lubricants, some products of their transformation and hydrocarbons.

6.2 Sampling

The American Society for Testing and Materials (ASTM) and forensic science working groups (e.g. Scientific Working Group on Gunshot Residue (SWGGSR)) provide internationally accepted protocols for sample collection, preparation, analysis and interpretation of results.

The areas from which GSR might be collected are wide ranging. Skin surfaces, vehicles (seats and seat backs, doors, windows, dashboards, headliners, interiors and exteriors), the surroundings of an incident, doors, windows, body parts, clothing and any other surfaces in the immediate vicinity of a firearm discharge might all be sample targets. Numerous techniques can be used for GSR sample collection and selecting the most appropriate one is important in ensuring maximum collection efficiency.

IGSR

Standard practice for the majority of UK forensic providers is to sample and analyse for IGSR, due to the well-established and validated methodologies. Currently, IGSR is shown to be evidentially more significant than OGSR. The techniques generally employed in the UK for recovery of IGSR are adhesive tape lifting (stubs or tapes), swabbing, and, less commonly, vacuuming. The more commonly used stub samples involve a sticky carbon tab mounted on a 12.5mm diameter aluminium stub (fig 26). The stub collection method involves dabbing the stub over the area of interest, until the tackiness has gone. Multiple stubs per location are used where the tackiness has subsided prior to the entire area being covered. It is crucial to ensure that a representative sample is taken (i.e. for hands, stubbing of entire palm areas, back of hands, and between thumbs and fingers).

Figure 26. Aluminium stubs with adhesive carbon surface used for GSR analysis.

OGSR

When sampling for OGSR, wet swabbing with a solvent and vacuuming are the recovery techniques which can be used. Promising early work for OGSR recovery and analysis from carbon adhesive stubs has also been achieved but will require further extensive testing and validation before incorporation into forensic casework.

6.3 Analysis

IGSR

The major methods for detection of primer/inorganic residues (IGSR) are analytical and qualitative. A number of other methods can be used to detect IGSR such as neutron activation analysis and atomic spectroscopy techniques. However, it is universally accepted that SEM-EDS (sometimes referred to as SEM-EDX) is used in forensic casework. SEM-EDS is a non-destructive technique which provides both morphological (size and shape) and elemental information. The SEM instrument should be capable of detecting particles of approximately 1μm (1/1000th mm) in diameter which are invisible to the naked eye.

Analysis by SEM – EDS currently provides a highly definitive method by assigning an elemental profile to an individual particle. An electron beam is used to image and analyse the chemical composition of the samples. Currently, it is the most reliable technique for the identification of individual particles consisting of lead (Pb), antimony (Sb) and barium (Ba) in various proportions. This combination of elements, along with a morphology indicative of having been produced by a molten process, is commonly accepted as characteristic of GSR. It might be reasonable to analyse a portion of the stub surface by employing an appropriate sampling plan and analytical protocol assuming a random distribution of particles on the stub surface.

OGSR

Following sample collection using an organic solvent, gas or liquid chromatography (GC and LC respectively) techniques with mass spectrometry (MS) detection are typically used for OGSR analysis. However, a generic analytical approach for the analysis of OGSR has not yet been established for routine casework within the international forensic community.

6.4 Classification

A limited number of primer formulations is used worldwide. These are not specific to a particular kind of ammunition or firearm. However, the composition of the IGSR particles detected reflects the nature of the primer used.

IGSR

The classification of IGSR (based on morphology and elemental composition) indicates whether particles are deemed characteristic or indicative of/consistent with GSR (Table A1 Appendix 1). Particles characteristic of GSR are defined as particles most likely to be associated with firearms or firearm-related sources, and thus have a composition which is rarely found in particles of any other known source. Indicative/consistent particles might be associated with firearm-related sources but could also originate from other unrelated sources such as pyrotechnics.

GSR particles are generally of sizes ranging from 0.5 – 10µm in diameter although sizes of up to 100µm have been reported. Figure 27 illustrates a typical 3 component lead (Pb)- barium (Ba)- antimony (Sb) particle from such an analysis.

Figure 27. A typical GSR particle image from SEM analysis.

Which combination of elements constitutes characteristic GSR depends on the type of primer used. The most common primers for handgun ammunition are based on the Sinoxid formulation, containing compounds of barium, antimony and lead. In addition to the above, other elements might be present providing discrimination such as aluminium (Al), tin (Sn), calcium (Ca), silicon (Si), and/or sulphur (S).

Lead-based ammunition (i.e. lead-containing primers) remains the most encountered ammunition in UK crime and the most widely used by UK police forces during operations and training. A mercury-fulminate based primer might be found in ammunition manufactured in Eastern Europe. Some of the newer primers are lead-free. Ammunition referred to as lead-free might contain one or more other elements including tin, titanium, zinc, aluminium, sulphur, calcium, potassium, chloride, copper, barium, antimony, strontium or silicon. There is a number of different lead-free primer formulations (non-toxic ammunition), none of which produces particularly distinctive residues unless specifically marked/tagged, generally with a unique identifier for that specific ammunition. Therefore, particles produced from this kind of ammunition can be difficult to identify/classify as GSR.

To date, lead-free primers are very rarely encountered in UK criminal work. Table A1 (Appendix 1) provides full details of the ASTM classification system which is adopted worldwide.

Within the UK, there is a tendency by some forensic practitioners to report GSR particles in terms of their classification types, based on a system devised by the former Forensic Science Service (FSS) of England and Wales. Types 1 to 3 in Table A2 (Appendix 1) are the residues typically encountered in casework.

OGSR

The analysis of organic compounds (OGSR) could provide valuable complementary information which might strengthen the value of GSR evidence. There are, however, no generally accepted guidelines for selecting target analytes, which will inform sampling and analysis protocols. With over 140 organic compounds associated with OGSR, it should be noted that some have not yet been identified in experimental studies. Moreover, some of these compounds are considered ubiquitous environmental pollutants, and thus their source apportionment could be questionable. Definitive guidelines for classification of characteristic OGSR materials have yet to be identified, but some criteria have been developed/proposed (see bibliography/reference section).

6.5 Interpretation

A case by case approach is recommended for the interpretation of GSR evidence as an individual may acquire GSR by a variety of different processes and all relevant information pertaining to the case must be considered. The presence of multiple characteristic particles as well as other particles indicative of GSR is generally sufficient for unequivocal identification of these particles as GSR. Therefore, it is important to understand the propositions which are being addressed by investigating teams.

For example, the presence of GSR on an individual can be the result of one of four possible scenarios:

- The individual has discharged a firearm
- The individual has directly handled or been in possession of a firearm
- The individual was in the near vicinity of a discharging firearm or
- The individual has been in contact with a surface contaminated with GSR.

This last scenario opens up the possibility of GSR contamination due to secondary transfer onto the suspect. Table A3 (Appendix 1) provides further details on types of transfer process related to GSR.

Current challenges in case interpretation include consideration of particles which might have originated from an environmental or occupational source, as opposed to a firearm discharge. Another area of consideration is the fate and behaviour of GSR materials. This includes distribution and deposition, transfer and persistence processes. The number of particles deposited initially will be in part dependent on the environmental conditions present at the time of the shooting. Additionally, the level of physical activity of an individual (or object) post deposition will have an impact on the rate of GSR loss. Typically, there is rapid loss of GSR particles within 2 hours post-discharge. Subsequent activity (e.g. washing) can result in further losses.

Source apportionment of GSR-like particles

The possibility of other sources of GSR-like particles is very important. If it were found that any other process or activity could produce particles with morphological and/or compositional characteristics indistinguishable from those of GSR then the value of such particles as forensic evidence would be greatly reduced. Such materials could come from any item which incorporates a primer (e.g. nail guns, blank-firing guns, flares, some vehicle airbags).

Some fireworks and other pyrotechnics can also produce particles similar to GSR and studies have shown that although the elements Pb, Ba and Sb may be encountered as part of the firework population, all three are not commonly encountered together in one particle. The following two component particles are seen in fireworks: Sb-Ba and Ba-Al. Usually the presence of other elements such as chlorine, potassium, sulphur, strontium, magnesium, or titanium may indicate a firework source.

Contamination

Armed police officers will have GSR on their hands and clothing (including body armour) from firing and handling their weapons and from their general work environment as well as from attending firing ranges. Armed police officers could be deployed to an operation straight from a training session, thereby increasing the likelihood of the presence of high to very high levels of GSR which scientific studies suggest may be on their clothing. Therefore, transfer of GSR from armed police officers to individuals can occur during the detention procedure through the physical handling of individuals, i.e. detaining them, searching them and in the deployment of plasticuffs. GSR can be transferred to the suspect’s hands, head/hair and clothing. The types of GSR detected on armed police officers will be related to the ammunition they use in training and operationally in hand guns, rifles and shotguns.

GSR can be transferred into vehicles if they have been the subject of a ‘hard stop’, especially if Hatton rounds (a shotgun round made for door breaching) have been discharged to blow out the tyres and/or stun grenades (flashbangs) deployed.

Individuals classed as recreational shooters (e.g. hunters, target shooters) will also acquire GSR on their hands and clothing through firearms activity. This should be considered a potential source of GSR together with any subsequent transfer to persons/objects which they encounter.

Environmental contamination

One might ask what is the possibility of contamination with GSR from the environment, e.g. at a railway station, or from a taxi. Studies have shown that GSR is not prevalent in the environment. Single characteristic particles of GSR have been detected on occasion. Therefore, although the possibility exists, in reality it is highly unlikely that an individual will be contaminated with significant numbers characteristic of GSR particles from the natural environment.

Firer or non -Firer?

Whilst large amounts of gunshot residue (GSR) can be deposited onto the clothing and person of someone who discharges a gun, similar amounts can also be deposited onto a person in close proximity to a discharging gun. In such cases it may be difficult to assess who might have carried out the discharge and who might have been a bystander.

At the current time the understanding of the transfer, persistence, recovery and background abundance of firearm residue is limited. Further information in relation to the interpretation of GSR can be found in the use of statistics in legal proceedings: A primer for courts [ref]

7. Firearms Classification

According to the Forensic Science Regulator, only those forensic laboratories /organisations accredited to the ISO17025 standard and to the Regulator's Codes of Practice and Conduct may provide firearms-related classification evidence to the criminal justice system. All individuals reporting scientific or technical work to the courts (whether called by the prosecution or defence) must declare compliance with this Code of Conduct, and firearms experts must fulfil their obligations under the revised Criminal Practice Directions. Such compliance with independent quality assurance organisations is intended to demonstrate the credibility and reliability of forensic science practitioners to the court and public and to minimise the risk of a miscarriage of justice. Similar safeguards are expected where experts give evidence in other jurisdictions (eg civil or coronial).

Forensic firearms experts refer to the firearms legislation, primarily the Firearms Act 1968, to classify firearms, ammunition and related items. In addition to understanding the somewhat arcane legal terminology, forensic scientists need an awareness of authority in order to signpost to the court which sections of a statute are said to have been contravened, and how. Given that over fifty years have passed since the enactment of the 1968 Act, it is not surprising that many amendments (at least twenty, see Reference section) have been made to try and keep pace with the changing patterns of criminal use of certain firearms. This has led to some complexity in the legislation, especially as some amendments have been of Acts which were not primarily concerned with firearms law. This complexity is the source of some of the disagreements which routinely occur between experts called by the prosecution and the defence.

Typically, the legislation has changed in response to a firearms mass shooting incident e.g. the Hungerford shootings in 1987 led to the Firearms (Amendment) Act 1988 and the shootings in Dunblane in 1996 to the Firearms (Amendment) Act 1997. Similarly, other changes to firearms legislation came about because of loopholes which the government has tried to close in the interests of public safety. Examples include introduction of the Anti-Social Behaviour Act 2003 which made it an offence to possess certain types of air guns which were commonly encountered in armed criminality in the UK until that time. As the firearms laws change, so do the types of weapons used by criminals and so do the items forensic scientists are asked to classify. Another evidence-based law change was the Violent Crime Reduction Act 2006 which limited the sale of imitation firearms, amongst other items. The Anti-Social Behaviour, Crime and Policing Act 2014 amended a section of the 1968 Act to prevent criminals who had served more than a specified term from possessing firearms or ammunition due to the high number of prohibited persons who were found in possession of such items. Following a review of firearms legislation by the Law Commission in 2015, the most recent reform was intended to provide statutory definitions in order to remove the subjectivity in interpretation which exists, and to modernise areas of law which had not kept up with technological advances and innovation. This most recent change was the enactment of the Policing and Crime Act 2017.

The aim of a classification statement or report is to provide the court with reasoned evidence supported by facts or expert opinion. The main parts of the Firearms Acts and associated legislation to which forensic scientists refer are sections 1, 2, 5, 57 and 58 of the Firearms Act 1968 as amended by other pieces of firearms legislation as previously described. Other guidance, such as Home Office Guidance on Firearms Law is available for reference, although such guidance is not statutory and carries little or no weight in court.

Typically, a gun or ammunition may be one of the following:

- unrestricted according to firearms law and may be freely possessed (unless used in the commission of an offence)
- restricted and require a firearms certificate in order to possess it (section 1)
- some shotguns can be legally possessed on a shotgun certificate (section 2)
- prohibited and require permission of the Secretary of State (section 5 (various))
- a firearm (section 57(1))
- an imitation firearm (section 57(4))
- an antique firearm (section 58(2))

Some prohibited weapons falling under Section 5, whist classified as firearms, do not constitute lethal barrelled weapons. Obvious examples are irritant spray devices and electronic stun-guns. Their classification, however, is often reported on by forensic scientists specialising in forensic ballistics.

Examples:

In simple terms, guns which can fire a projectile with kinetic energy in excess of 1 joule at the muzzle are classified as firearms. Guns which cannot are classified as imitation firearms. Air guns have been known to cause fatal injuries and therefore some air guns will be classified as firearms. Low powered air guns are classified as imitation firearms.

Whether a gun is a small arm (handgun such as a pistol or a revolver or a sub-machine gun) or a long arm (a shotgun or rifle), the questions typically needing an answer in order to classify them are:

- is it a firearm or an imitation firearm?

- If it is a firearm, can it fire in fully automatic mode, what calibre is it, how old is it (could it be considered an antique firearm), what size is it, how many cartridges can its magazine hold (shotguns), how does it operate (is it self-loading or pump-action for example), is the barrel rifled or smooth bore, what sort of ammunition or missile does it discharge, is it a signalling device or muzzle loading gun, is the gun disguised as something else, is it an air gun that uses a specific type of cartridge, has the gun been modified or converted in some way?

Where it is possible to answer all these questions and the relevant section of the law includes clear definitions, a definitive classification will be given by stating explicitly which section of the Firearms Act 1968 applies.

If it is not possible for whatever reason to answer some or all of the above questions categorically, an expert opinion might be given. If such an opinion is given, it must be made abundantly clear that it is no more than an opinion, which therefore allows another expert to disagree and may, even if unchallenged, not be accepted by a jury.

If uncertainty exists about classification, the forensic scientist must provide all the options with any relevant contextual information which may assist the court, and the court must be invited to decide on the basis of all the other available case-related information at its disposal.

On occasion, items can be classified according to more than one section of the Act or by more than one part of section 5 of the Act and, if this is the case, the forensic scientist should provide all possible and reasonable options to assist the court in its decision-making.

Firearms experts examine firearms, ammunition and related items to identify them as far as possible. If an item cannot be identified, it might not be possible to classify it. A forensic scientist's examination requires the following:

- recording any markings on the items and interpreting their possible meaning(e.g. are the markings genuine, do they tell the forensic scientist anything about the age, manufacture, provenance or safety of the weapon/ ammunition?)

- taking measurements where size is relevant (e.g. what is the calibre of the gun/ammunition?) using calibrated equipment

- testing the item in question to determine whether it is in working order

- comparing test fired samples from a recovered gun to outstanding (unsolved) crimes to see if the gun can be linked to earlier shootings. This might be relevant if a gun is potentially an antique, and the defendant is claiming it was possessed as a curiosity or ornament.

Due to the lack of statutory definitions in certain sections of firearms law, some subjectivity in interpretation of the law has arisen. These following areas are typically contentious, and as a result, there is commonly disagreement in the expert opinions of forensic scientists called by the prosecution and the defence.

The most common areas of disagreement are

- whether a gun is capable of causing a lethal injury
- whether a gun is an antique
- whether a part is a component part
- whether ammunition is of an obsolete calibre
- whether substances are considered noxious
- whether an item may be regarded as disguised as another object
- whether a cartridge case or bullet was fired from a particular gun
- whether something was designed or adapted

In addition, disagreement is common on how much work or specialist knowledge is required to modify or convert particular items.

Unfortunately, as a result, national inconsistencies have arisen when the law has been interpreted differently in different cases and by different forensic scientists.

8. The Future

The engineering principles of most common firearms in use today were determined well over a hundred years ago, and many of the principles of forensic ballistics covered in this document have also changed little over the past century. Nevertheless, there are areas that will undoubtedly change forensic ballistics in years to come. These are likely to be with regard to advances in technology and also in strengthening the science behind the techniques used.

Various reports over the last ten years have challenged the scientific validity of aspects of forensic ballistics, particularly on the linking of bullets and cartridge cases to an individual gun. It is likely that more research is needed to counter or uphold these criticisms and maintain the confidence of the scientific community. In particular, there is an absence of ground truth data, double blind trials and error rates, all of which have been highlighted, and it is for ballistics experts to counter these arguments with robust empirical evidence which supports the science.

New technology will provide both opportunities and challenges. The automated systems used to scan across thousands of cartridge cases and bullets recovered from crime scenes are becoming more accurate as algorithms are refined. Whilst we are still probably a long way from replacing experts, the technology will continue to improve to the extent that larger databases can be searched more accurately, potentially enabling many more crimes to be linked. It is also possible that these algorithms will provide statistical match probabilities, much like DNA profiling, thereby reducing the subjective element inevitable in current reporting.

Regarding GSR analysis, scanning electron microscopy techniques for analysis and confirmation is considered the ‘gold standard’ and is likely to remain the technique of choice. Further research on submicron and nanoparticle GSR analysis is needed to evaluate the efficacy of these highly sensitive analyses for use in forensic casework. Concurrently, the fate and behaviour of such particles must be assessed. The ability to determine a full chemical profile detailing IGSR and OGSR materials also should be considered. This has been shown to be possible from a single sample, but further research and testing is required.

The development of 3D printed weapons has been given much recent publicity, with particular concerns about widespread access to illegal firearms and the potential opportunity for terrorists to make undetectable weapons. Many of these fears have proved to be unfounded, in that current technology produces plastic weapons incapable of withstanding the pressures generated when a cartridge is fired. Of more concern, however, is the ability to manufacture weapons printed in metal. Such weapons are already in existence and are understood to produce identical microscopic markings on bullets and cartridge cases. Similarly, a move to cartridge cases manufactured using polymers, rather than brass and other similar metals, might significantly reduce the microscopic markings upon which ballistics experts rely to link them to an individual firearm.

The engineering principles of most common firearms in use today were determined well over a hundred years ago, and many of the principles of forensic ballistics covered in this document have also changed little over the past century. Nevertheless, there are areas that will undoubtedly change forensic ballistics in years to come. These are likely to include advances in technology that strengthen the robustness of the science behind the comparison techniques.

Various reports over the last ten years have challenged the scientific validity of aspects of forensic ballistics, particularly in linking bullets and cartridge cases to an individual gun. Currently such links are made on the basis of subjective opinion only and no objective methodology is used.

There is a current absence of ground truth data sets and robust scientific study to provide objective empirical evidence in support of the subjective opinions of forensic ballistics experts.

More research is needed to address these limitations so that the legal community can continue to have confidence in the ability of forensic ballistics experts to link bullets and cartridge cases to an individual gun. In terms of individual practitioner competence, double blind trials and error rates also need to be undertaken.

New technology will provide both opportunities and challenges. The automated systems used to scan across thousands of cartridge cases and bullets recovered from crime scenes are becoming more accurate as algorithms are refined. The error rates associated with the use of such automated systems must be generated and understood.

Currently statistically-based match probabilities are not provided in forensic ballistics examinations and larger databases are required to enable such objective probabilistic interpretations to be undertaken thereby reducing the subjective element inevitable in current reporting.

Regarding GSR analysis, scanning electron microscopy techniques for analysis and confirmation is likely to remain the technique of choice. Further scientific research on submicron and nanoparticle GSR analysis is needed to evaluate the efficacy of these highly sensitive analyses for use in forensic casework. The ability to determine a full chemical profile detailing IGSR and OGSR materials also should be considered. This has been shown to be possible from a single sample, but further research and testing is required.

Concurrently, the transfer and persistence once transferred as well as the background abundance of such particles is not well understood and needs further scientific study.

The development of 3D printed weapons has been given much recent publicity, with particular concerns about widespread access to illegal firearms and the potential opportunity for terrorists to make undetectable weapons. Many of these fears proved unfounded, in that current technology produces plastic weapons incapable of withstanding the pressures generated when a cartridge is fired. Of more concern is the ability to manufacture weapons printed in metal. Such weapons are already in existence and are understood to produce very similar microscopic markings on bullets and cartridge cases. Similarly, a move to cartridge cases manufactured using polymers, rather than brass and other similar metals, might significantly reduce the microscopic markings upon which ballistics experts currently rely to link them to a firearm.

9. References

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The relevant firearms legislation is as follows:

- Firearms Act 1968
- The Firearms (Dangerous Air Weapons) Rules 1969
- Novelties (safety) Regulations 1980
- Firearms Act 1982
- Crossbows Act 1987
- Firearms (Amendment) Act 1988
- 1991 EC Directive (91/477/EEC) on the control and acquisition and possession of weapons
- Firearms (Amendment) Act 1992
- The Firearms Acts (Amendment) Regulations 1992 No.2823
- The Firearms (Amendment) Rules 1992 No.2824
- The Firearms (Dangerous Air Weapons) (Amendment) Rules 1993

- Firearms (Amendment) Act 1994
- Firearms (Amendment) Act 1997
- Firearms (Amendment) (No.2) Act 1997
- Anti-Social Behaviour Act 2003
- Violent Crime Reduction Act 2006
- The Violent Crime Reduction Act 2006 (Realistic Imitation Firearms) Regulations 2007
- Firearms (Amendment) Regulations 2010
- The Violent Crime Reduction Act 2006 (Specification for Imitation Firearms) Regulations 2011
- Anti-Social Behaviour, Crime and Policing Act 2014
- Policing & Crime Act 2017

10. Appendices

Appendix 1 – Supplementary tables

Table A1: Classification of IGSR compounds relevant for the confirmation of GSR materials

Characteristic particle compositions	Indicative/consistent particle compositions	Commonly associated with GSR
Pb-Ba-Sb Pb-Ba-Sb (Al) Pb-Ba-Sb (Sn) Pb-Ba-Sb (Si, Ca)	Ba-Al Pb-Sb Pb-Ba Pb-Ba-Ca-Si Ba-Ca-Si (S) Sb-Ba (Fe, S)	Sb Ba (S) Pb
-Lead free primers Gadolinium, titanium and zinc (Gd-Ti-Zn) Gallium, copper and zinc (Ga-Cu-Zn)	*--Lead free primers* Titanium and zinc (Ti-Zn) Strontium (Sr)	

Table A2. GSR classification scheme developed by the FSS categorising GSR into different types based on elemental composition.

Type 1 Pb-Ba-Sb (Characteristic)
Type 2 Pb-Ba-Sb-Al (Characteristic) and Ba-Al (Indicative) if with Pb (Characteristic)
Type 3 Pb-Ba-Sb and Sn (Characteristic) and Ba-Sb-Sn (Indicative)
Type 4 Pb-Ba-Ca-Si with or without Sb (Characteristic) and Ba-Ca-Si without Pb (Indicative)
Type 5 Ba-Ca-Si-Sn with or without Pb (Characteristic)
Type 6 Hg-Sb-Ba with or without Pb and with or without K,Cl (Characteristic if Hg present in residue, Indicative if not)
Type 7 Hg-Sb-Ba-Sn with or without Pb and with or without K,Cl (Characteristic). Will also produce particles of Sn-Sb (Indicative)
Type 8 Ba-Pb with Ba > Pb peak in most particles. (Mostly associated with rimfire ammunition, can also contain Si and P)
Type 9 Ti-Zn (Lead/Heavy metal-free ammunition)

TABLE A3: Transfer processes relating to GSR.

Transfer type	**Description/ method of transfer**
Primary transfer (1°)	The initial discharge of a firearm results in the direct deposition of GSR particles onto surfaces in near proximity e.g. the shooters hands; the firearm; a bystander who was in the proximity of firearm discharge.
Secondary transfer (2°)	Contact with surfaces/individuals contaminated with GSR particles during primary transfer may result in subsequent cross-transfer to a surface that was not present during initial discharge. Secondary transfer may occur under an array of circumstances, for example: - Direct contact with a shooter e.g. handshaking immediately after firearm discharge - An individual not present at the time of discharge handling objects contaminated with GSR during primary transfer e.g. discharged firearm - GSR transfer to ‘clean’ clothing from a contaminated garment through direct contact.
Tertiary transfer (3°)	Contact with materials contaminated by secondary transfer.
Quaternary transfer (4°)	Contact with materials contaminated by tertiary transfer.

Appendix 2 - Case examples

Case examples

1. A 9mm Parabellum calibre self-loading pistol with a rifled barrel that is of a modern calibre, with a 10cm long barrel and which is 22cm in overall length. The pistol is in working order.

   Classify as a firearm and a prohibited weapon on the basis of its size (Firearms Act 1968, Firearms (Amendment) Act 1997).

2. A 12-bore smooth bore gun with a magazine that can hold four cartridges and a barrel length of 28 inches and an overall length of 50 inches.

   Classify as a section 57(1)(a) firearm and firearms certificate restricted weapon on the basis of the magazine capacity. (Firearms Act 1968, Firearms (Amendment) Act 1988).

3. An 8mm calibre blank self-loading pistol with a blocked dummy barrel that cannot fire any missiles.

   Classify as a section 57(4) imitation firearm on the basis that it is not a lethal barrelled weapon (Firearms Act 1968).

4. A 5.5mm calibre air rifle which has a full-length barrel and stock and is capable of firing air gun pellets with more than 1 joule of kinetic energy but less than 12 ft/lbs of kinetic energy.

   Classify as a section 57(1)(a) firearm but one that is not especially dangerous and therefore does not require a firearms certificate. (Firearms Act 1968, Firearms (Dangerous Air Weapons) Rules 1969).

5. A 5.5mm calibre air rifle with a full-length barrel and stock which is capable of firing pellets with more than 12 ft/lbs of kinetic energy.

   Classify as a section 57(1)(a) firearm which is especially dangerous and requires a section 1 firearm certificate to possess. (Firearms Act 1968, Firearms (Dangerous Air Weapons) Rules 1969).

6. A live round of 6.35mm Browning calibre ammunition with a round nosed bullet.

   Classify as section 57(2) ammunition that is section 1 firearms certificate restricted (Firearms Act 1968).

7. An electric shock device in working order.

Classify as a section 57(1)(b) firearm that is a section 5(1)(b) prohibited weapon (Firearms Act 1968).

8. A working electric shock device that looks like a mobile telephone but does not work as one.

   Classify as a section 57(1)(b) firearm and a section 5(1)(b) prohibited weapon and offer the opinion to the court that it may be disguised as a mobile telephone (section 5(1A)(a), Firearms Acts (Amendment) Regulations 1992).

9. A working electric shock device that looks like a torch and also works as a torch.

   Classify as a section 57(1)(b) firearm and a section 5(1)(b) prohibited weapon and offer the opinion to the court that it may be disguised as a torch (Firearms Act 1968, section 5(1A)(a), Firearms Acts (Amendment) Regulations 1992).

10. An old large calibre (that is obsolete according to guidance) revolver that was made in 1874 (is 145 years old) which has a barrel length of 15cms and an overall length of 25cms that is not submitted with ammunition and was recovered as part of a deceased's estate who was a collector.

    Classify as a section 57(1)(a) firearm, which may benefit from the exemption in section 58(2) (Firearms Act 1968).

11. An old large calibre revolver as above that was recovered from a vehicle during a search with homemade modified modern ammunition that was made to fit the gun and was shown to have been used in a shooting 3 months previously.

    Classify as a section 57(1)(a) firearm that is old and may benefit from the exemption in section 58(2) (firearms Act 1968) but which is also a section 5(1)(aba) prohibited weapon (Firearms Act 1968, Firearms (Amendment) Act 1997).