

GSR Gunshot Residue: The Chemistry Behind a fired Weapon

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ABSTRACT

Gunshot residue (GSR) is a complex collection of microscopic particles and chemical substances produced when a gun is fired. It is formed through the rapid combustion of propellant, the decomposition of primer compounds, interactions between ammunition and firearm components, and the passage of the projectile through the weapon. As a result of this process, GSR can contain both inorganic and organic substances.

Traditionally, elements such as lead, barium, and antimony have been with inorganic gunshot residue (GSR) derived from primers. However, the chemical composition of modern ammunition can vary significantly, making the interpretation of GSR more dependent on a combination of analytical findings rather than the detection of any single element.

Forensic testing of GSR is used to determine whether a person or object was exposed to a recently fired gun and whether substances related to gunshot are present on a particular surface. Several analytical techniques have been developed for this purpose, including scanning electron microscopy combined with energy-dispersive X-ray spectroscopy (SEM-EDS), atomic absorption spectroscopy, inductively coupled plasma mass spectrometry, Among these, SEM-EDS is of particular importance because it can provide information about both the morphology and elemental composition of individual particles.

Key word: Gunshot residue, X-ray spectroscopy, Inorganic gunshot, Decomposition

1. INTRODUCTION

This review discusses the chemical reactions of firearm exhaust gases, the formation and composition of gastrointestinal strains (GSRs), the differences between inorganic and organic residues, the methods used for collection and analysis, factors affecting the stability of residues, and the major limitations associated with interpretation. The review also outlines how changes in ammunition composition and advances in device analysis are impacting modern forensic GSR testing.

Firearms are an important source of physical and chemical evidence in forensic investigations. When a firearm fires, it produces more than just a bullet and a sound. Large numbers of findparticles are also produced and dispersed around the firearm. These particles are collectively called bullet debris.

The study of GSR includes principles of forensic science, analytical chemistry, materials science and physics. It is important to understand the chemistry of the GSR as it contains information related to ammunition, primer construction, propellant, and firearm components.

Historically, forensic laboratories often focused on detecting specific inorganic elements associated with conventional ammunition. Lead, barium, and antimony became particularly important because they were

commonly found in primer residues. However, ammunition technology has changed significantly. The manufacture of lead-free and environmentally conscious ammunition may contain various combinations of metals and organic compounds.

Therefore, modern GSR testing requires a comprehensive approach. The mere presence of any particular element does not prove that the bullet was fired from a gun. Environmental particles, occupational exposures, and other sources can sometimes produce chemically similar substances. Therefore, the morphology of the particles, elemental composition, organic components, background information and appropriate controls may all be relevant. To understand the chemistry behind the process of firing a weapon, it is necessary to consider the events that occur inside the cartridge after it is fired. An intense chemical reaction produces hot gases and solid or condensed reaction products. These products interact with the gun and ammunition and are subsequently deposited on surrounding surfaces.

OBJECTIVES OF THE REVIEW

The main objectives of this review are as follows:

1. To explain the chemical origin of the bullet remains.
2. To describe the major components of GSR.
3. To differentiate between inorganic GSR and organic GSR.
4. To discuss the chemistry of primer and propellant combustion.
5. To review important techniques used for GSR analysis.
6. To investigate the factors affecting GSR deposition and stability.
7. To discuss the limitations inherent in forensic interpretation.
8. To highlight the recent developments in GSR examination.

2. HISTORICAL DEVELOPMENT OF GSR EXAMINATION

Along with improvements in analytical chemistry came the development of forensic examination of residue from firearms. Early approaches attempted to identify chemical substances deposited on the shooter's hands or surrounding surfaces after a firearm was fired.

Historically, chemical spot tests were used to detect certain specific components of smoke from firearms. Although these methods contributed to the development of forensic GSR testing, they had some limitations regarding specificity and sensitivity.

The advent of instrumental analytical methods brought significant changes in this field. Microscopes made it possible to examine individual particles, while elemental analysis provided additional information about their composition.

The combination of scanning electron microscopy and energy-dispersive X-ray spectroscopy has become particularly important because it allows the physical characteristics and elemental composition of a particle to be examined simultaneously. Recently, advanced mass spectrometric techniques have made testing of the organic components of GSR even more widespread.

The historical development therefore represents a transition from relatively simple chemical testing to multidimensional analytical approaches.1. WHAT IS GUNSHOT RESIDUE?

Residue is the substance produced when a gun is fired which is later deposited or spread into the surrounding environment.

GSR is not a single chemical substance. It is a heterogeneous mixture whose composition depends on many factors, including:

Types of gun

Ammunition manufacturing Primer composition Propellant composition
Bullet and cartridge manufacturing Firearm status
Firing position Environmental conditions

GSR can be in the form of extremely small particles.

Some particles may be deposited directly onto hands, clothing, or nearby objects, while others may remain temporarily suspended in the surrounding air.

Because remains are chemically and physically diverse, forensic laboratories typically evaluate multiple characteristics rather than relying on a single compound or element.

2. CHEMISTRY OF A FIREARM DISCHARGE

A cartridge usually consists of a projectile, propellant, and primer inside the cartridge shell. When the primer is activated by the firing mechanism, an intense chemical reaction occurs in the primer.

This reaction produces heat, gases and particles. These products initiate the combustion of the propellant. The resulting gases rapidly increase the pressure inside the cartridge shell.

The pressure causes the projectile to move rapidly through the barrel. During this process, the primer, propellant, cartridge shell, projectile, and materials generated from the firearm may be included in the discharge plume.

A simplified conceptual sequence is as follows:

Initiation of primer → combustion of propellant → Rapid gas production → pressure development → motion of projectile → formation and dispersion of residue.

The actual chemistry is far more complex as ammunition formulations vary between manufacturers and cartridge types.

3. COMPONENTS CONTRIBUTING TO GSR

3.1 PRIMER

Primer is one of the most important sources of GSR. Traditional primer formulations consist of an initiating explosive, fuel, and oxidizing components

Historically important primer-related compounds include lead-based, barium-containing, and antimony-containing substances.

When the primer begins to act, a rapid chemical change occurs in these substances. The resulting products may be

condensed into fine particles.

Modern primer formulations may differ from traditional structures. Some ammunition is designed to reduce or eliminate particular heavy metals. This makes the interpretation of GSR more complex.

3.2 PROPELLANT

The propellant provides the energy needed to propel the projectile through the barrel of the gun.

Smokeless propellants based primarily on energetic organic materials are used in many types of modern ammunition. Depending on the composition, nitrocellulose, nitroglycerin, and stabilizer-related compounds may be present.

During combustion, the components of the propellant undergo rapid decomposition and oxidation. Not every molecule is completely converted into gaseous products. Some partially reacted compounds and combustion products may contribute to organic pellet residues.

3.3 PROJECTILE

Projectile remains may contribute metals or other materials to the environment.

Depending on construction, the projectile may contain or be surrounded by materials such as lead, copper or copper alloys. The interaction between the projectile and the barrel may also produce fine material.

3.4 CARTRIDGE CASES

Metal particles may be released from the cartridge case when fired. Brass, steel, and other materials can be used depending on the ammunition design

Small particles may migrate into the discharge environment as a result of mechanical interaction and high temperature conditions during firing.

3.5 FIREARM COMPONENTS

Some substances may also be added to the residue from the firearm itself. Mechanical and thermal interactions may occur between components such as the barrel, chamber, and firing mechanism during firing.

Therefore, the GSR structure should not automatically be considered a direct chemical fingerprint of the primer alone.

4. INORGANIC GUNSHOT RESIDUE

Inorganic GSR (IGSR) primarily consists of inorganic elements and compounds associated with primers, ammunition, and firearm materials.

Traditional primer residues are often associated with the following combinations:

Lead (Pb) Barium (Ba) Antimony (Sb)

The importance of these elements stems from their historical prevalence in traditional primer formulations.

However, a simple statement like "lead + barium + antimony equals GSR" is scientifically inadequate. Similar elemental combinations can be found in other sources, and modern ammunition may not have the traditional elemental pattern.

For this reason, the shape of the particles and the connections of the elements are important in examining them through a microscope.

5. BIOLOGICAL GUNSHOT RESIDUE

Organic gunshot residue (OGSR) consists primarily of organic compounds derived from propellant and primer materials.

Possible organic components include the following:

Nitrocellulose related materials nitroglycerin

stabilizer plasticizer

Centralite-type compounds

Diphenylamine and related stabilization compounds other ammunition-specific biological components

Its exact composition varies according to the manufacture of ammunition.

The importance of OGSR analysis is rapidly increasing because organic compounds can provide information that can complement inorganic particle analysis.

Techniques such as gas chromatography–mass spectrometry (GC–MS) and liquid chromatography–mass spectrometry (LC–MS) can be used to investigate selected organic compounds.

6. INORGANIC GSR VS ORGANIC GSR

Features: Inorganic GSR | organic gsr

Major sources Primers, Firearms and Ammunition Propellants and Primers

General analytical information structure | molecular structure fundamental.

Example: Lead, Be, Sb and other elements.

Nitro-organic compounds, stabilizers and related substances
Important technology SEM-EDS | GC-MS/LC-MS
Key Benefits: Particle Morphology
Fundamental structure Chemical characteristics of organic compounds
Major range Potential environmental/
Commercial Sources Degradation and analytical complexity
Combined testing can provide a more comprehensive chemical picture than relying on any one category.

7. MORPHOLOGY AND CHEMICAL COMPOSITION OF PARTICLES

GSR particles are often extremely small.

Their morphology can provide useful forensic information.

Particles produced during a gun's firing may exhibit specific shapes as a result of melting, vaporization, condensation, and rapid cooling.

SEM examination allows individual particles to be seen at high magnification. EDS can then provide the elemental spectrum associated with the selected particle.

Its forensic importance derives from a combination of the following:

Particle Morphology + Elemental Composition + Particle Distribution + Relevant Information

Instead of locating just one element.

8. GSR EVIDENCE COLLECTION

It is important to collect samples correctly as GSR may be destroyed or contaminated after being collected. Samples should be collected as quickly as possible using clean and certified collection materials. Hands are important locations for sampling, while clothing and other surfaces can also be examined.

Important precautions include avoiding unnecessary contact, using appropriate protective equipment, collecting control samples as needed, clearly labeling samples, and maintaining the chain of custody.

9. ANALYTICAL TECHNIQUES FOR GSR

SEM-EDS:

Scanning electron microscopy–energy dispersive X-ray spectroscopy (EDS) is an important method for inorganic GSR analysis. SEM provides images and morphology of particles, while EDS provides elemental information. This allows investigation of individual particles, although their source cannot always be traced from elemental composition alone.

AAS and ICP-MS:

Atomic absorption spectroscopy and inductively coupled plasma mass spectrometry can detect metals and other elements associated with GSR. ICP-MS is highly sensitive, but bulk analysis can provide little information about individual particles.

XRF:

X-ray fluorescence provides fundamental information with relatively limited sample preparation and can be useful for suitable GSR samples.

GC-MS and LC-MS:

These techniques are primarily used for the analysis of organic gunshot residue (OGSR). GC-MS is useful for volatile or thermally stable compounds, while LC-MS can analyze a wide range of organic compounds.

10. FACTORS AFFECTING GSR DEPOSITION

GSR deposition varies depending on several factors, including:

Gun type and design

1. Ammunition and primer composition
2. number of bullets fired
3. gun distance
4. environmental conditions
5. Post Discharge Activities

These factors can influence both the quantity and distribution of detectable residues.

11. CONTINUITY AND LOSS OF GSR

GSR does not remain permanently on hands or clothing. Its residues can be detected by washing, sweating, rubbing, touching objects, changing clothes and normal daily activities.

Therefore, absence of GSR does not prove that a person did not fire the gun. Similarly, detected particles should be interpreted carefully because their transfer from other surfaces is possible.

12. FORENSIC INTERPRETATION

GSR results should be interpreted taking into account the circumstances of the case. The discovery of residue indicates that particles similar to a bullet fired from a firearm have been found, but it does not automatically prove that the person fired the shot.

Possible causes may include direct gunshot, secondary transfer, or exposure to related background sources.

Therefore, the findings must be kept within the limitations of the analysis method.

13. FALSE POSITIVE RESULT AND BACKGROUND RESOURCES

Some commercial, industrial, and environmental materials may contain elements that are traditionally associated with GSRs, such as lead or barium. Therefore, the presence of any one element is not sufficient to confirm that a firearm was fired.

Particle morphology, elemental composition, appropriate controls, and background information must be considered when interpreting.

14. LIMITATIONS GSR ANALYSIS

Major limitations include:

Non-uniqueness of individual elements

Variation in ammunition chemistry

environmental pollution

Loss of residue after discharge

sampling limitations

Changes in ammunition technology

These limitations demonstrate why GSR findings require careful scientific interpretation.

15. RECENT DEVELOPMENTS IN GSR ANALYSIS

The main objective of modern GSR research is to obtain more chemical information from very small samples. Important developments include automated SEM-EDS analysis, high-resolution mass spectrometry, advanced OGSR analysis, chemometric methods, multi-element profiling, and research on lead-free ammunition.

Combined analysis of organic and inorganic GSRs can yield a more comprehensive chemical profile.

16. ROLE OF CHEMISTRY IN FORENSIC FOREARM INVESTIGATION

Chemistry plays an important role in understanding the formation and identification of GSRs. The composition of the primer, propellant, and firearm components affect the chemical properties of the residue.

This entire process can be represented as follows:

Ammunition Chemistry → Firearm Firing → Residue Formation → Deposition → Sampling → Chemical Analysis → forensic interpretation

17. FUTURE PERSPECTIVE

Future GSR research is expected to focus on improved OGSR detection, lead-free ammunition, automated particle classification, advanced statistical interpretation, portable analytical equipment, and integration of organic and inorganic residue analysis.

Standardized analytical protocols can also improve uniformity among forensic laboratories.

18. CONCLUSION

Bullet residue is one of the most chemically diverse pieces of forensic evidence produced during a gunshot. Its composition is influenced by primer chemistry, propellant formulation, projectile material, cartridge construction, and gun components.

Traditional inorganic GSR have often been associated with lead, barium and antimony, while modern ammunition can produce quite different chemical profiles. Detection of GSR has evolved from relatively simple chemical tests to sophisticated instrument-based methods. SEM-EDS is particularly useful for investigating individual inorganic particles because it combines morphological and elemental information. Additionally, GC-MS and LC-MS provide important opportunities for the study of organic components.

Caution is needed in interpreting GSR.

Because the remains may be lost, moved or

Confused with particles from other sources.

Therefore, GSR should not be treated as a separate piece of evidence. Its chemical characteristics, sampling conditions, analysis method, and circumstances of the case must all be considered.

Overall, the chemistry of bullet residue demonstrates how analytical chemistry can contribute to forensic investigations.

Continued research on ammunition composition, organic residues, and improved instrumentation methods is expected to improve the scientific investigation of firearms-related evidence.

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