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Review Article

Current perspectives in the interpretation of gunshot residues in forensic science: A review

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ABSTRACT

The traces produced when a firearm is discharged can provide important information in cases when questions regarding a possible association of the firearm with a person of interest (POI), time since discharge or shooting distance are raised. With advances in technology, the forensic challenges presented by these traces, known as gunshot residues (GSR), are moving from the analytical domain to the interpretation of the analytical results. Different interpretation frameworks are currently competing. Formal classification of particles, using standards such as that produced by ASTM, focusses only on evaluation of evidence at the sub-source level. Another approach, based on the application of Bayesian reasoning – namely the case-by-case approach – has been proposed that allows evaluation of evidence in regards to activity-related questions. This alternative approach allows an evaluation of the evidence that is more closely aligned to judicial and investigative aims. This paper critically presents the state of the art in regards to GSR interpretation in a holistic manner.

Contents

1. Introduction

The traces produced by the discharge of a firearm – called gunshot residues (GSR) or firearm discharge residues (FDR) [1] – can provide valuable information for highlighting and assessing relationships between an individual and a sequence of activities involving the use of a firearm. GSR can also assist by allowing a wound entry hole to be distinguished from an exit hole or estimating a shooting distance [2–4]. The latter are particularly important for the reconstruction of firearm-related cases. GSR may also be relevant to establish the kind of ammunition used at the time of the shooting [5–9].

GSR can be defined as volatile, gaseous products as well as particulate matter formed after a firearm is discharged [1]. The

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residues are composed of burnt and unburnt particles arising from the primer (inorganic GSR – IGSR), propellant (organic GSR – OGSR) and other materials coming from the cartridge case, the projectile(s) and the firearm itself [10–14]. The residues escape predominantly from the muzzle of the firearm. As a result, GSR may deposit on the target as well as surfaces surrounding the discharged firearm, which include the shooter's hand, face, hair and on objects in the close vicinity [15–18]. The distribution of GSR is influenced by different factors such as the location (outdoor, indoor) [19], whether appropriate ammunition has been used in the firearm and the barrel length [20].

Scanning Electron Microscopy coupled with Energy Dispersive X-ray spectroscopy (SEM-EDX) is currently the most used technique for IGSR particle detection and chemical characterisation. It allows the morphological shape and the elemental composition of particles to be analysed [9,21–24]. Several analytical techniques have been successfully utilised for the detection of OGSR [25] such as gas chromatography (GC) [26–30], micellar electrokinetic capillary electrophoresis (MECE) [31–34], Raman spectroscopy [35–37], desorption electrospray ionisation–mass spectrometry (DESI–MS) [38–40] and liquid chromatography (LC) [41–51].

However, the analytical aim relates to only one dimension of the forensic scientist's task. The other dimension relates to the investigative and judicial aims of forensic science. In this dimension, forensic scientists work commonly with several stakeholders in the system such as investigators, prosecutors, defence and finally the court to help the trier of fact reach a verdict [52,53]. From an investigative point of view, the forensic scientist can be asked to provide fast information focusing on the incident by generating hypotheses for sustaining and orientating investigators during the initial phase of the inquiry [54]. After that phase, when a person of interest (POI) has been charged, the forensic scientist has to assess their test outcomes given a set of propositions relating to the person of interest and the case [54,55] in order to assist the court in the decision-making process. To approach the management of uncertainty relating to the uniqueness of traces and past nature of each event, a framework to enhance the interpretation of evidence[1] has been developed [57–60]. This framework can aid in the clarification of the meaning of the analytical findings in reference to the allegations presented by the court and the specific contextual circumstances surrounding the criminal case under investigation.

In regards to GSR interpretation, of primary importance is the classification of residue as inorganic GSR particles [21]. This classification concerns the uncertainty associated with attributing the origin of residues as firearm discharge rather than something else without considering the case in question (i.e., the classification is at the sub-source level). Thus, current challenges encountered during trials concern a possible environmental or occupational source of particles rather than firearm discharge [61]. At the next level of questioning, attention then needs to be concentrated on the traces persistence and the possibility of secondary transfer, arising through contact between the POI and police officers [62,63] or other persons who have handled or discharged a firearm, to the possibility that the POI discharge or handle a firearm prior to the crime under investigation.

The role of the scientist is to provide an expert opinion about the forensic evidence in the case under investigation. Therefore, to deal with chronological factors and circumstantial information of the event, a "case-by-case" approach was proposed by Romolo and Margot in 2001 [64]. In this paper, they also introduced the Bayesian theorem as interpretation framework to gunshot residue events.

2. The American Society for testing and materials standard: a formal approach

Seminal research relating to the interpretation of IGSR was published in 1979 [21,65,66] from a report published in 1977 [67] about the detection and specificity of GSR analyses. The particle compositions and spheroidal, non-crystalline morphology were initially classified by Wolten et al. (1979) in regards to their specificity to GSR [21]. This classification generated the first interpretive framework for gunshot residues. Afterwards, the American Society for Testing and Materials (now ASTM) developed standards [68] to avoid misinterpretations due to environmental sources of GSR-like particles. One classification under this standard relates to "characteristic" particles, which may be directly linked to firearms-related events such as discharging gun, or contact with or close proximity to a discharged firearm. Through this classification, the forensic scientist compared simply the analytical outcomes to the ASTM standard to express their conclusion [68]. The results that are therefore related to a specific event are compared to a general and theoretical idea of the particles' origin suggested by the ASTM standard [64,68]. In practice, as a protection against false positives, forensic scientists take into consideration the composition of the entire population of particles present in the recovered traces and not only one or few particles that meet the ASTM criteria. Romolo and Margot [64] described the previous ASTM standard [68] as a formal approach due to the lack of consideration of the case circumstances during the interpretation.

The results of a survey conducted by DeGaetano et al. in the early 1990s [24] demonstrated that in 41% of laboratories, detecting one particle containing the characteristic configuration was considered sufficient to indicate GSR analyses as positive, despite variations that exist among experts about the significance given to one detected GSR particles. This suggested that a court outcome could potentially rest on the detection and classification of a single characteristic particle without consideration of whether case circumstances tend to support or refute that opinion. These observations were supported four years later by another survey conducted by Singer et al. [69]. Table 1 provides the modern, ASTM encapsulation of the views of Wolten et al. and others subsequently [21,64–66,70–72].

Particles having the compositions mentioned in Table 1 may also contain one or several of the following elements: silicon (Si), calcium (Ca), aluminium (Al), copper (Cu), iron (Fe), sulfur (S), phosphorus (P), zinc (Zn) (in combination with copper), and nickel (Ni) (rare and only in combination with copper and zinc), zirconium (Zr), tin (Sn), potassium (K) and chlorine (Cl) [73]. According to the latest ASTM standard [73], the criteria for

Table 1
Modern classification of particles composition detected with a SEM-EDX [73].

Characteristic (exclusive to GSR)	Consistent with GSR
(1) Lead–barium–antimony (Pb–Ba–Sb)	(1) Lead–antimony (Pb–Sb) (2) Antimony–barium (Sb–Ba) (3) Barium–calcium–silicon–sulfur (in trace level) (4) Barium–aluminium (sulfur in trace level) (5) Lead–barium (Pb–Ba) (6) Lead (Pb) (7) Barium (Ba) (sulfur in trace level) (8) Antimony (Sb)

[1] According to the ENFSI guideline "*The term 'evidence' is generic. From a strict scientific point of view, evidence refers to outcomes of forensic examinations (findings – results of observations, measurements and classification that are made on items of interest), at a later point, may be used by legal decision-makers in a court of law to reach a reasoned belief about a proposition. Evidence should be a term kept for lawyers.*" ([56], pp. 19–20)