Forensic Science International 183 (2009) 33–44

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Distribution and properties of gunshot residue originating from a Luger 9 mm ammunition in the vicinity of the shooting gun

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ARTICLE INFO

Article history:
Received 7 April 2008
Received in revised form 29 September 2008
Accepted 7 October 2008
Available online 28 November 2008

Keywords:
Forensic science
Gunshot residue
SEM-EDX
Distribution of properties of particles in a function of the shooting range

ABSTRACT

Examinations of various features of gunshot residue (GSR) collected from targets in a function of the shooting distance as well as from hands and the forearm, front and back parts of the upper clothing of the shooting person were performed with SEM-EDX. GSR samples were obtained using Walther P-99 pistol and Luger 9 mm ammunition of Polish production. The experiments were designed in such a manner that the substrates for collecting GSR reminded the ones usually obtained for examinations within criminal cases. Results of the performed examinations in the form of parameters describing GSR particles: the number of GSR, proportions of their chemical classes as well as their sizes revealed a dependence on the shooting distance both, in the direction of shooting and backwards, i.e. on the shooting person. The analysis of the distribution of particles in the vicinity of the shooting gun may be utilised in description of the general rules of the dispersion of GSR as well as in the reconstruction of a real shooting case.

1. Introduction

Gunshot residues (GSR) are related to the place and time of firing a gun. The analysis of GSR is being routinely performed in order to solve particular problems such as differentiation of entry and exit wounds, estimation of the shooting distance, establishing the kind of ammunition used, tracing the trajectory of a projectile and relating an individual to a shooting incident. Fulfilling any of these tasks may contribute to a shooting incidence reconstruction.

Metallic particles originating from the primer of ammunition are thought to be the most characteristic gunshot residues for their exceptional chemical content and morphology that reveals features of molten and suddenly cooled matter. That makes them highly valuable evidence in relating a person with the fact of using a firearm, however they may also be very informative in other aspects of shooting incidence investigations. Although many sensitive analytical methods can be applied for identification of the characteristic gunshot residues, only scanning electron microscopy with energy dispersive X-ray spectrometry (SEM-EDX) was recognised as the most specific one. It enables an examiner to observe simultaneously the characteristic morphology of a GSR particle and check its elemental content without prior damage of the object and so is a well-established method of identification of this kind of evidence in forensic laboratories. It does not require complicated sample preparation. Among few methods of collecting GSR for examinations with SEM-EDX method the most popular one is lifting microtraces by multiple pressing of an adhesive material to the substrate of interest, e.g. the suspect's hands, face, hair and clothing. One of the important studies concerning the quality of an expertise in the field of GSR examinations by means of SEM-EDX focuses on proficiency testing aiming at the precision and sensitivity of the analytical instrumentation. A great progress was recently achieved in the development of identical artificial GSR test samples fulfilling the requirements of standards ISO 5725 and ISO 13528 [1,2].

The fundamental problem of GSR examinations for forensic purposes is an evaluation of the analytical results. A classification scheme of metallic particles introduced by Wolten et al. [3–5], later modified by Wallace and McQuillan [6] was widely accepted by gunshot residue examiners and used for more than two decades. According to the scheme three-component particles containing lead, antimony and barium are unique primer residues. Accompanying two- and one-component particles are indicative for gunshot, since particles of similar elemental contents could have been found in other circumstances. This formal approach is now being under discussion in the view of recent publications on the residue of fireworks, the dust of car brake pads as well as on the residue of the newest non-toxic ammunition. Although still very

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doi:10.1016/j.forsciint.2008.10.010

rarely and in different environment, one can find a single lead–antimony–barium particle that reveals a similar to GSR morphology [7]. This inspired the European GSR examiners to rename the 'unique' and 'indicative' particles back to 'characteristic' and 'consistent with GSR', and revise the chemical composition of the appropriate classes of particles [8]. The scheme includes now particles originating from special brands of ammunition marked with gallium or gadolinium (being supplied, e.g. for German and Dutch police) as well as from some non-toxic ammunition types in addition to the traditional ones containing lead, antimony and barium compounds.

However, the classification scheme does not provide answers to questions: what quality and quantity of particles would be significant evidence in certain case and how this particular evidence would contribute to achieving an opinion by the decision-makers. Thus, Romolo and Margot suggested another approach to the assessment of GSR as an evidence called a case-to-case approach, e.g. based on Bayesian principles [9]. In 2005 Avermate presented interesting examples of this manner of interpretation of GSR examinations in casework and demonstrated that despite of lack of numerical data likelihood ratio can be evaluated qualitatively and utilised in formulation of conclusion in the expert's report [10]. Recently, Biederman and Taroni proposed to introduce a probabilistic approach such as Bayesian network for a joined evaluation of two types of evidence: the identification of the firearm (marks on the projectile) and the assessment of the shooting distance (GSR) [11]. The authors provided a theoretical framework for this combined evaluation of the uncertainty of the evidence. For the estimation of shooting distance they suggested visualisation of nitrite compounds as the residue of the propellant using a modified Griess test and counting the number of the revealed particles within patterns of various shooting distances. Unfortunately, the authors used hypothetical numbers instead of empirical data leaving the reader with doubts, whether quantitative results to be obtained in reality would be enough repeatable for the proposed statistical requirements. So far, the shooting distances are in practice estimated by visual inspection of the pattern of interest in relation to a series of test shots patterns. This applies also to patterns visualised by means of analytical instrumentation such as millimetre-X-ray spectrometry [12] and imaging in infrared light [13].

It ought to be admitted that the spatial expansion of GSR, the time of their presence in the crime scene as well as dispersion of their properties depending on the distance from the muzzle are still not thoroughly recognised. Some ideas on the range of GSR and time sedimentation were gathered performing single experiments in controlled conditions, including preparation and distribution of horizontal accumulating targets around the shooter at various heights [14–16]. In shooting cases, however, often a person that becomes a victim is initially in the upright position. In such cases experts receive for examinations the victim's clothes that acted as vertical targets as well as the shooter's clothes in addition to samples collected from his hands. Sometimes also cartridge cases found on the crime scene are available. An attempt was done by Cheylan et al. to explore the forensic potential of linking suspects to a crime through investigations of the chemical contents of GSR samples collected from the cartridge case, the barrel, the target and the breech [17]. The samples were compared taking into account the proportion of lead, antimony and barium measured by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) as well as $^{208}Pb/^{206}Pb$ and $^{208}Pb/^{207}Pb$ isotope ratios measured by Sector Field-Inductively Coupled Plasma Mass Spectrometry (SF-ICP-MS). The authors revealed variation of GSR composition along the gun to target path, e.g. approximately the same proportion of lead originating from the primer (about 80%) was found in samples taken from the barrel and the breech. About 93% of lead recovered in the cartridge case came from the primer and the remaining 7% from the core of projectile, whereas as much as 44% of the lead found on the target came from the core of the projectile.

A comparative study of the chemical content and morphology of GSR collected from the shooter's hands and from inside of a spent cartridge obtained as a result of a single shot with full metal jacket (FMJ) Luger 9 mm ammunition of various producers was performed using SEM-EDX method [18]. Examples of ammunition representing the following three types of primer were examined: the oldest one (but still in use) based on mercury fulminate, the traditional one based on lead styphnate or lead azide and one of the newest lead-free types. The study has shown some similarities as well as great differences between residue collected from the two substrates. Whereas the residue present inside the cartridge case revealed the chemical composition directly resulting from the composition of the primer, to the chemical composition of the airborne particles contributed materials of the core and the jacket of the projectile. The greatest modification of the chemical composition of the airborne GSR, in comparison to that of particles found inside the cartridge case, took place in the case of the lead-free ammunition with a tin plated projectile as well as in the case of the mercury fulminate primed ammunition. Tin originating from the surface of the projectile in the lead-free ammunition and similarly, lead originating from the uncovered part of the projectile of the mercury fulminate primed ammunition were present in GSR collected from the shooter's hands in the appropriate experiments. Thus, it has been concluded that the distribution of the chemical elements in the gunshot residue is determined by the direction of the movement of the products of detonating primer and burning propellant as well as the kind of materials that were used to construct the ammunition and gun.

The presented study was aimed at establishing whether application of SEM-EDX method would provide an information on possible changes of sizes of GSR as well as the proportions of their chemical classes depending on the distance from the muzzle, both in the direction of shooting and the opposite one. An example of mercury fulminate primed ammunition was chosen for the examinations for two reasons. Firstly, this type of ammunition is being produced and widely used in Poland and so becomes a frequent subject of forensic expertise. Secondly, in this ammunition lead is not present in the primer mixture, however the metal jacket does not cover the bottom of lead bullet core. Thus, it was expected that lead containing particles to be possibly detected in the surroundings of a shooter could be related to the origin of the bullet core and so to provide an information on the mechanism of dispersion of GSR using this type of ammunition.

2. Experimental

2.1. Materials

The subjects of the study were inorganic gunshot residues collected from hands of the shooter, from the sleeves, the front and back upper parts of his upper clothing and from a target in the distance of 50 cm, obtained within the same single shot. Moreover, microtraces were collected from targets shot in the following distances: 10, 20, 30, 70 and 100 cm, in a separate experiment.

In order to obtain the investigative material in the form of metallic particles originating from firing a gun two types of experiments were performed. The first experiment was performed in such a manner that a person, who did not shoot for more than 3 days before, dressed in a white cotton lab coat, made a single shot. After a shot had been performed, the traces were collected from the shooter's hands immediately at the shooting gallery and the clothing and targets were secured for further investigation in the laboratory. The second experiment consisted in test shots to targets placed at distances of 10, 20, 30, 70 and 100 cm. In the experiments each target was covered with a fresh paper target and a 40 cm $\times$ 40 cm fragment of a white cotton fabric. There were performed three rounds of each experiment.