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A study of transfer and prevalence of organic gunshot residues

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ABSTRACT

The main goal of the present study was to determine the amounts and distribution of organic gunshot residues (OGSR) on the shooter's upper body and clothing after discharging a pistol. A preliminary study was also performed to evaluate the prevalence of OGSR in the general population as well as in a police laboratory environment. In the transfer study, results indicated that OGSR are not only transferred to the hand of the shooter, but also to other parts of the upper body. Thus, wrists and forearms also represent interesting targets as they are washed less frequently than hands. Samples from the face and hair of the shooters resulted in no OGSR detection just after firing. It was also observed that the concentrations recovered from clothing are generally higher compared to the same skin area. Prevalence in both general (n = 27) and police populations (n = 25) was low. No OGSR was detected in the samples from the general population and only two samples from the police population were found positive.

1. Introduction

Chemical analysis of gunshot residues (GSR) can provide useful information for the reconstruction of events involving the use of firearms. This could include linking a person to such an event, an estimation of shooting distance and trajectory, bullet entry and exit point identification or simply determining the circumstances of a case and verifying the veracity of a testimony [1–3]. Additional information concerning the type of firearm and ammunition used as well as the time since discharge can also be useful [4–7]. GSR consists of a complex mixture of organic and inorganic material originating from the firearm, the ammunition and the combustion products formed during the discharge [8,9]. GSR particles are not only propelled towards the target, but also in the direction of the shooter through the muzzle and, in significantly lower quantities, through other apertures of the firearm, such as the ejection port or the trigger notch. Therefore, GSR may be transferred to different parts of the shooter's body and also to other people or surfaces close to a firearm discharge [3,10–12].

Current analysis methods for GSR focus mainly on the analysis of inorganic GSR (IGSR), which consist of metallic particles from the primer, the projectile, the cartridge and the weapon. Scanning electron microscopy (SEM) coupled to energy-dispersive X-ray spectroscopy (EDX) is the most commonly used analytical method for the detection of IGSR. However, the absence of inorganic particles on the surface in question, the prevalence of metal particles in the environment and the introduction of heavy metal-free or "non-toxic" ammunition has the capacity to produce false positives and negatives. Therefore, the analysis of complementary target molecules might prove necessary to further increase the probative value of the evidence [13]. The analysis of organic gunshot residue (OGSR) represents an interesting added value to operational practices. OGSR consist of completely burned, partially burned and unburned particles, mainly originating from the propellant and lubricants [4,9,14,15]. More detailed information on the different formulations of the propellants and the various additives has been reviewed previously [9,15,16].

In recent years, numerous studies, which aimed to develop various analytical methods, as well as collection and extraction procedures for OGSR molecules, were published [15]. Among these, a wide range of protocols using liquid chromatography coupled to mass spectrometry (LC–MS) was proposed, allowing the identification and quantification of a number of propellant stabilizers and organic explosives [17–23]. Despite significant progress in the development of analytical methods regarding OGSR analysis, specific forensic questions still remain unanswered. Considering an OGSR research cycle, the determination of target compounds and development of analytical techniques are well documented, whereas only a few publications aimed at studying the transfer, persistence and prevalence of OGSR. However, these

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parameters are critical when interpreting analytical results [24]. Furthermore, knowledge about the persistence and prevalence of GSR in a specific environment are essential to assess the risk of possible contamination [25]. To date, most of the articles relative to these issues are based on the study of IGSR and data still have to be collected for OGSR in order to implement reliably such approaches in practice.

Several studies have focused on transfer and persistence of explosive molecules [26–31]. While some of these compounds are present in OGSR, many others are structurally different so it is not possible to infer the transfer mechanism (and subsequent persistence) from studies involving explosives. Some studies specifically involving the transfer and persistence of OGSR on the shooter's body have also been reported and are summarized in Table 1.

A number of key observations and trends have emerged from the studies presented in Table 1. OGSR can be transferred to hands and clothing with the highest amounts detected for NG as it is a major component of smokeless powders. Stabilizer amounts (a minor component of smokeless powders) were present at lower levels and require an analytical method offering superior sensitivity. Nevertheless, no systematic study of the distribution of OGSR on the shooter's body has been conducted to date. Regarding persistence, a trend showing a longer persistence on clothing than on hands appeared. Some studies reported the absence of OGSR detection on hands 30 min to one hour after discharge [33,36], whereas others obtained positive results after two or more hours [40,44]. The difference in these results have been explained by several factors such as activities undertaken by the shooter following discharge, the sample collection methods applied or the instrumental technique used (sensitivity). On clothing, NG was detected up to five days showing far better persistence probably thanks to better retention from the fabric [32]. Again, this result is likely attributable to the larger amounts of this compound being transferred to the shooter. Due to the lack of a systematic study, no upper time limit for OGSR detection has been proposed yet. Studies showed that some OGSR compounds, mainly stabilizers, can be absorbed by the skin due to their lipophilic properties. Evaporation is also another mechanism for OGSR losses. According to these results, the best targets might be EC, 2-nitroDPA and 4-nitroDPA [43]. Finally, OGSR might be less susceptible to secondary transfer than IGSR due to these properties [41].

Besides the transfer and persistence of OGSR, some authors also studied the background prevalence of these compounds. Different population studies were conducted using various analytical protocols, as well as different target molecules [16,45–49]. At several locations in England, a total of 337 specimens were taken in various public places, as well as from hotels, houses, vehicles and clothing. Additionally, 255 specimens were also obtained from police stations [45]. Using GC-TEA and GC–MS, the authors reported that four of the 337 specimens collected from public places were positive for ng levels of RDX, two for ng levels of NG and two for ng levels of 2,4-DNT and RDX. 24 of the 255 specimens collected from police sites were positive for ng levels of NG, three for RDX and one for PETN. A follow-up study was performed with 501 specimens collected in the four major UK cities, namely Birmingham, Cardiff, Glasgow, and Manchester [46]. The authors reported that one of the 501 specimens collected from public places was positive for ng levels of RDX, two for ng levels of NG and one for ng levels of 2,4-DNT. Furthermore, over 300 specimens were collected from 28 cities across the U.S. and then analyzed by GC-TEA for explosives residues [47]. No organic explosives were detected. In 2016, 70 specimens were also obtained from police officers and from the furniture of four Pittsburgh police stations [48]. Using LC–MS/MS, EC was only quantified in four specimens, one from an officer and three from a police station. Regarding prevalence of OGSR on people, two studies are targeting OGSR on hands. A first prevalence study was performed in the U.S. on 100 volunteers from the general population with no positive results using micellar electrokinetic capillary electrophoresis (MEKC) [16]. Another prevalence study conducted on 73 people, belonging either to the general or to the police population of Morgantown, West Virginia, showed that the proportion of positive results for OGSR found in the specimens analysed by IMS was less than 5% [49]. All the authors of the aforementioned studies concluded that the detection of high explosive and OGSR traces is rare in public places and in the general population. The few positive results in police sites are not surprising, given that law enforcement personal are in regular contact with firearms.

While there has been significant focus on persistence and prevalence, minimal recent research has been conducted on the transfer and distribution of OGSR on the shooter's body and clothing. As the analytical techniques have rapidly evolved, typically leading to an increase in sensitivity and also selectivity, it might be unreasonable to base the interpretation of results on data acquired using less sensitive instrumentation. Moreover, the amount of data regarding the background prevalence of OGSR molecules useful in the interpretation at the source level is limited, because the studies were conducted in two countries only, whereas data from the country/region in question should be available for interpretation in actual casework. Finally, some studies targeted organic explosives and not organic stabilizers that are the main targets in OGSR analysis. Consequently, due to the differences in chemical structure, data cannot be extrapolated. Therefore, more data is required in order to evaluate the value of OGSR traces in a particular context with regard to competing hypotheses. As already mentioned, target compounds are well known and analytical techniques are sufficiently well developed to look further in the research cycle. Transfer, persistence and prevalence data are essential to build interpretation models and implement OGSR analysis in forensic laboratory routine.

The present study aims to examine the transfer and transferred amount of OGSR simultaneously collected on different parts of the shooter in order to assess optimal collection areas for detecting residues. Furthermore, a preliminary prevalence study was performed to determine if the target compounds are frequently found within selected populations, the first one generally not exposed to firearms and the second comprising staff from an operational forensic science laboratory.

2. Material and methods

2.1. Experimental protocols

2.1.1. Transfer study

Shooting sessions were conducted in an indoor shooting range located in a specific building section with the ventilation turned off. Extraction and analysis of the specimens were performed in a separate laboratory in another section to minimise any potential contamination. A semi-automatic 9 mm Parabellum Sig Sauer P226 was used for all experiments. The firearm was completely dismantled, cleaned and lubricated before the study. After every OGSR collection, the outer parts of the pistol were cleaned using a piece of paper wetted with ethanol to avoid any contamination when touching the firearm. The ammunition used was 9 mm Parabellum from Geco (batch 61 SE). The shooters were asked to wash their hands with soap before entering the shooting range. A blank sample of both hands, as well as the pistol hand grip was taken to verify if they were clean. The pistol was loaded by a third person as the shooters were not allowed to touch any surface except the firearm at the time of firing. Then, the shooters were