Research article

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The secondary transfer of gunshot residue: an experimental investigation carried out with SEM-EDX analysis

James French,[a]* Ruth Morgan[b] and James Davy[c]

Gunshot residue (GSR) is produced when a firearm is discharged and is routinely used in the forensic reconstruction of incidents involving firearms. SEM-EDX with automated detection and analysis software was used to investigate the extent of GSR secondary transfer following the discharge of a firearm. A series of experiments, which mimicked real-world scenarios, was set up to explore these under-researched mechanisms. The findings demonstrate that relatively large amounts of GSR can be transferred to an individual immediately after the discharge of the firearm, through contact with the hands of the shooter or handling of the gun. While varying between runs, over 100 particles were transferred via a handshake in one instance, and it was found that even very large particles (60–100+ μm) were transferred from the shooter to the second individual via a handshake. The findings have implications for forensic investigations, including highlighting the need to sample from individuals who might have been involved in transfers and underscoring the importance of achieving accurate particle counts using the SEM-EDX method. Most importantly, the findings suggest that the presence of GSR (especially in small quantities) may not always indicate that a person discharged a firearm and that the possibility for misidentification of the shooter exists, as does the potential to distinguish shooters from those who have acquired GSR through secondary transfer. Further experiments employing automated SEM-EDX are suggested, which will add to our understanding of GSR transfer evidence and continue to improve the accuracy of interpretations which are presented in court. © 2013 The Authors. X-Ray Spectrometry published by John Wiley & Sons, Ltd.

Introduction

The forensic investigation of incidents involving firearms routinely involves attempts to detect gunshot residue (GSR) on samples taken from different surfaces. The results of GSR analyses are often used in crime reconstruction to determine a variety of details including the shooting distance/trajectory,[1–3] the characteristics of the firearm/ammunition combination[4,5] and the nature of wounds (entry or exit).[6,7] Meanwhile, the detection of GSR on a sample taken from the hands, face or clothing of an individual may indicate that an individual has been in the vicinity of a discharging firearm or has made contact with surface onto which GSR has previously been deposited.

GSR (sometimes termed firearm discharge residue) is produced when a gun is fired and is composed of solid 'partially burnt and unburnt propellant particles and combustion products from the priming compound' along with compounds from the bullet, cartridge and firearm (Heard,[8] p.241). These materials cool and condense to form small, typically (but not exclusively) spherical particles, which are deposited on the hands, clothing and face of a shooter, and on surfaces in the vicinity. Many analytical methods have been developed and trialled for the detection of GSR (see Romolo and Margot[9] and Dalby *et al*.[10] for a comprehensive review), yet the most established and refined technique is SEM-EDX. Employing this method involves a dual approach to detection and analysis – particles are morphologically detected via their size/shape characteristics and are elementally examined for the presence of certain elements.[11] GSR particles owe their specific morphological and chemical characteristics to the conditions of their formation.[12] Their chemical composition will be dictated chiefly by the elements found in the primer. Consequently, GSR may be found to contain lead, barium and antimony, or combinations such as lead and barium only. Other primers contain mercury and can result in GSR consisting of elemental combinations such as mercury and antimony (for a comprehensive review of the composition of GSR produced by different primers see Wallace[13]). The presence of these elements can be detected using SEM-EDX. Certain environmental settings and activities, however, have been identified as sources of particles which are similar to GSR, highlighting the potential for misidentification (e.g. [14,15],[16]). Careful examination of particles and an awareness of the context in which they are found are therefore necessitated. Manually carrying out analysis using SEM-EDX is restrictively slow,[17] and developments in automating the detection and analysis process have facilitated significant reductions in the time taken to reliably analyse a sample.[18]

While the methods of detecting GSR have been developed, arguably less work has been carried out, which contributes to our understanding of the dynamics of GSR, particularly its transfer properties. Understanding these mechanisms is crucial

* *Correspondence to: James French, Department of Security and Crime Science, UCL, London, UK. E-mail: james.french.09@ucl.ac.uk*

a Department of Security and Crime Science, UCL, London, UK

b JDI Centre for the Forensic Sciences, UCL, London, UK

c Earth Sciences, UCL, London, UK

when interpreting the presence of GSR recovered from the hands of a suspect. The secondary transfer of GSR is an underexplored area and one in which little empirical research has taken place. 'Secondary transfer' describes the movement of trace evidence from the site of original deposition to a second surface that was not involved in the initial transfer. Investigations into secondary (and further) transfer in the literature include the works by Jackson and Cook[19] and Grieve *et al*.[20] for fibres, Gaudette and Tessarolo[21] for scalp hair, Van Oorschot and Jones[22] for LCN DNA, and Charles and Geusens[23] with regard to trace particulates in general. With regard to GSR, studies have confirmed that subjects can acquire GSR during arrest,[24] and that the presence of limited amounts of GSR on the hands of firearm-carrying officers[25] and in police vehicles and facilities[26] creates the potential for limited secondary transfer contamination. Meanwhile, Basu *et al*.[27] confirmed that GSR could be transferred to the hands through the handling of a fired gun. However, our understanding of these secondary transfers, beyond the potential for contamination by police, remains relatively limited, and their potential significance is unexplored. If such transfer mechanisms are applicable to GSR evidence, particles could, in theory, be transferred from a shooter prior to apprehension, thus incriminating an unconnected individual (Figure 1). In addition, this would also represent an apparent 'loss' of material from the original site of deposition. Consider an example where an individual who fired a gun then met an accomplice and shook their hand or perhaps exchanged the firearm for disposal. A secondary transfer of GSR in these instances could, in theory, result in the accomplice being mistaken for the shooter. While Lindsay *et al*.[28] found that in certain conditions, shooters and bystanders could not be distinguished on the basis of GSR counts, the relative GSR counts and particle characteristics on samples taken from shooters, and subjects who have made contact with a surface carrying GSR have not been fully explored.

There is a need to experimentally investigate plausible scenarios in which secondary transfers may occur. Such work will enhance our ability to accurately assess the likelihood that a secondary transfer has taken place in a forensic situation. Morgan *et al*.[29] note that experimentation that mimics forensic reality contributes to our understanding of trace evidence behaviour and therefore enhances our ability to interpret it within an investigative context. Experimentation may be informed by knowledge of the types of scenarios encountered in an investigative context. Accordingly, the present study represents an initial exploration of GSR secondary transfer, which establishes the underlying mechanisms and the degree to which transfers can occur in these kinds of scenarios. The following research questions were addressed:

1. Can GSR particles undergo secondary transfer to an individual who was not present at the time of firing?
   ·In what quantities?
   ·Are particles of all sizes involved in the transfers?
2. What are the practical implications for the collection, analysis, interpretation and presentation of GSR evidence?

In answering these questions using an experimental approach combined with SEM-EDX, the investigation also assessed the suitability of this method for carrying out similar studies into the dynamics of GSR and for the analysis of secondary transfers in real-world forensic contexts.

Materials and methods

To address these questions, a series of experiments was carried out in collaboration with the Surrey Police Tactical Firearms Unit. A SIG Sauer P226 9-mm self-loading pistol was used for all of the experiments and was loaded with 9-mm Luger 95 grain jacketed soft point 9P1 ammunition (manufactured by FEDERAL Ammunition). Each firing consisted of five rounds.

Samples were taken from the hands of subjects using ½ inch aluminium SEM stubs covered in self-adhesive carbon discs (TAAB Laboratories, UK) and were dabbed onto the entire surface of the hands 50 times. This sampling method has been employed extensively in studies of GSR.[30] Particular attention was paid to covering the entire surface and ensuring that the webbed area between thumb and forefinger was adequately sampled.[31] Sampling took place following each experiment, without delay, to ensure that the full extent of any transfer could be measured. Sampling took place a distance of 15 m from the point of firing and stubs were placed in individual sealed sample holders to prevent the effects of fallout of airborne GSR and cross-sample contamination.[8],[32] In all experiments, the subjects involved washed their hands thoroughly with soap and water (apt for the removal of GSR[33]), dried them with disposable towels and had a control sample taken before the experimental run began. Three experimental firing scenarios were designed. In the interests of ensuring ecological validity, these experiments mimicked the hypothetical forensic scenarios involving post-firing contact outlined previously.

Scenario 1 – straight firing

In the first scenario the shooter, following hand washing and control sampling, fired five rounds before being sampled. This scenario was set up to provide a measure of the GSR that was transferred to the hands of the shooter during firearm discharge.

Scenario 2 – firing followed by handshake

As in scenario 1, the shooter was control sampled after hand washing and fired five rounds. On completion, the shooter shook hands with a second participant (who was remote from the discharge and who had washed their hands and had been control sampled) whose hands were then sampled in the standard manner. This scenario mimicked a situation in which a shooter met or came into contact with an associate or unconnected individual after a shooting incident.

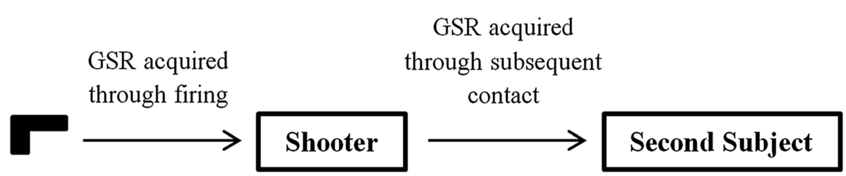

Figure 1. Hypothetical secondary transfer to second individual following deposition of GSR on shooter during firearm discharge.

Scenario 3 – firing followed by firearm exchange

In this scenario, firearm discharge was followed by the shooter handing the pistol to the second participant (whose hands were washed and control sampled) who held it briefly and returned it before being sampled. This represented a situation in which a firearm had been passed or returned to an accomplice for disposal, for example, following a shooting incident.

The samples derived from the experiments were carbon coated and then analysed for the presence of GSR. Sample analysis was carried out using a JEOL JSM-6480LV fitted with an Oxford Inca X-sight Energy Dispersive Spectrometer and automated GSR detection and analysis software (INCAGSR) (operating conditions in Table 1). The 'Unique' and 'Indicative' GSR particle counts and individual particle spectra were examined after each analysis run, and a sample of the features was manually verified. Instances where a single particle had been erroneously treated as two or more separate particles by the detection software were manually rectified as necessary.

Results

Particle counts

Particle counts from the samples taken during the three experimental scenarios are displayed in Tables 2–4 and are displayed graphically in Figure 2. It is important to note that all nine measures relate to nine different firings – no runs of scenarios 2 or 3 were carried out alongside a run of scenario 1.

The results from scenario 1 (straight firing) indicate that there was considerable variation in the quantity of GSR recovered from the hands of the shooter between the three runs. The firearm becoming dirty over the course of the three runs – while reflecting that in real life, firearms will not necessarily be cleaned between firings – could have contributed to this variation. However, in all three runs, the number of particles recovered was markedly larger than the number derived from any secondary transfer sample (from scenarios 2 or 3). Variability was also exhibited by the particle counts in scenario 2. However, the counts demonstrate that relatively large numbers of GSR particles were secondarily transferred to the subject via a handshake with the shooter, the highest being in run three (129). Meanwhile, the results from scenario 3 – while again exhibiting a degree of variability – all reveal significant amounts of transfer from the recently discharged firearm to the second handler. Generally, the amount of transfer between shooter and handshake participant (scenario 2) observed was higher than that which took place between the fired gun and the second handler (scenario 3).

Table 1. Operating conditions for the sample analysis using INCAGSR

Conditions for automatic search using INCAGSR, Oxford Instruments, UK	Setting
Magnification	200×
Accelerating voltage	20 kV
Working distance	10 mm

Table 2. GSR particle counts for scenario 1, runs 1, 2 and 3

Scenario 1		
Run 1	Run 2	Run 3
206	335	443

Table 3. GSR particle counts for scenario 2, runs 1, 2 and 3

Scenario 2		
Run 1	Run 2	Run 3
88	30	129

Table 4. GSR particle counts for scenario 3, runs 1, 2 and 3

Scenario 3		
Run 1	Run 2	Run 3
86	18	14

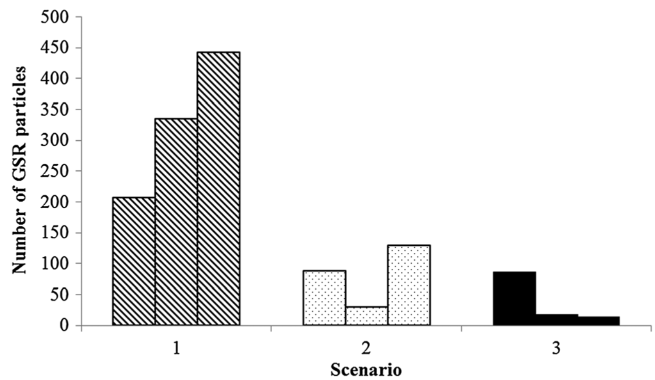

Figure 2. Graph showing GSR counts for (from left to right) scenario 1, runs 1, 2 and 3; scenario 2, runs 1, 2 and 3; scenario 3, runs 1, 2 and 3.

Particle sizes

In a study by Basu *et al.*,[27] size classes were created into which the GSR particles were sorted. For the present study, seven classes of particle sizes were created (0–0.99, 1–2.99, 3–4.99, 5–9.99, 10–29.99, 30–99.99 and 100+ μm). Particle size data for each run of each scenario are displayed in Table 5.

In all runs of all scenarios (with the exception of run three of scenario 3), the modal class of particles was 1–2.99 μm, with the vast majority of particles across all experiments measuring under 10 μm in length. The runs of scenarios 1 and 2 exhibited very similar average particle sizes, with the average of each of the six experiments ranging between 4.09 and 4.71 μm. The distributions of particles among the size classes were also comparable. In all runs, over half of the recovered particles measured under 3 μm, while each run yielded at least one particle that fell into the 30–99.99 μm category. Meanwhile, in five of the six runs, at least one particle that measured 10–29.99 μm was recovered. This suggests that a full range of particles (from very small to very large) was transferred from the shooter to the second subject when hands were shaken. However, when the subject handled the discharged firearm in scenario 3, the average size of the transferred particles departed from that of scenarios 1 and 2 – it was higher in runs 2 and 3 (6.96 and

Table 5. Particle size data for each run of scenarios 1, 2 and 3. Average particle and maximum particle sizes are also displayed

	Scenario 1			Scenario 2			Scenario 3		
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
0–0.99 μm	20	51	56	8	6	20	18	4	0
1–2.99 μm	112	163	225	40	12	73	50	6	1
3–4.99 μm	39	58	82	19	7	17	12	3	5
5–9.99 μm	23	39	52	15	4	11	2	1	6
10–29.99 μm	7	18	21	4	0	6	4	3	2
30–99.99 μm	5	6	7	2	1	1	0	1	0
100+ μm	0	0	0	0	0	1	0	0	0
Total number of particles	206	335	443	88	30	129	86	18	14
Average particle size (μm)	4.09	4.13	4.11	4.71	4.62	4.21	2.61	6.96	6.17
Largest particle (μm)	66.05	81.40	83.55	64.39	57.22	102.46	20.35	41.44	18.03

6.17 μm, respectively) and was lower in run 1 (2.61 μm). The distribution of particles varied between runs and differed in some respects to the distributions of particles in scenarios 1 and 2. For example, no sub-micron particles were recovered in run three, while only run 2 yielded a particle measuring between 30 and 99.99 μm. In terms of the largest particles encountered, scenarios 1 and 2 were again fairly similar, with the largest consistently being 60+ μm across the runs of these two scenarios. This again suggests that a full range of particle sizes was transferred from shooters to subjects via the handshakes. However, the largest particles encountered in scenario 3 tended to be smaller (20.35 μm in run 1, 41.44 μm in run 2 and 18.03 μm in run 3). The largest particles generated during discharge, it seems, tended to be deposited on the hands rather than on the firearm to later be transferred to a firearm handler. Notably, the largest particle encountered across all nine experiments measured 102.46 μm and was transferred to the subject via a handshake with a shooter in run 3 of scenario 2.

Discussion

The results provide strong evidence that secondary transfer mechanisms can result in the transfer of GSR particles to an individual who was not present when the firearm was discharged (research question one). Particles may be transferred to the hands of a second individual via an interpersonal (hand-to-hand) contact and also via a contact with a recently discharged firearm, the latter finding corroborating Basu *et al.*[27] Contrary to investigations of potential GSR secondary contamination (Gialamas *et al.*[25] and Berk *et al.*[26]), the secondary transfers staged here involved relatively large numbers of particles and suggest that secondary transfer is highly possible after a shooting. It must be noted, however, that the transfers in this study represent an ‘extreme’ case in which the contact was made immediately after firearm discharge, meaning that the maximum amount of GSR was present on the ‘donor’ surface (the shooter’s hand or the firearm) at the time the contact was made; very little decay would have taken place. Notwithstanding this, the experiments revealed that as many as 129 particles were transferred via a handshake, and it is likely that even with a delay between the firing and the contact, a transfer involving a detectable number of particles could take place. The same finding is indicated by the results from the firearm handling in scenario 3, although these transfers involved smaller quantities of GSR (with the exception of run 1). Furthermore, the population of particles detected on the subject following a secondary transfer suggests that, in theory, a detectable tertiary transfer may even be possible. It should be noted that variability in levels of GSR deposition between firings (and by logical extension, between simulated transfers) is not unprecedented[28],[34] and was to be expected in the results.

Secondary transfers from the shooter to the subject via a handshake indicated that these sorts of transfers can involve a full range of different sized particles and that the range of particles recovered from the subject will be representative of those that were primarily transferred to the shooter. Notably, the experiments revealed that even the very largest GSR particles (60–100+ μm) may be transferred from shooter to subject. This represents a novel observation with regard to GSR secondary transfer and is perhaps surprising given that a previous study[35] into GSR contamination found that transfers (albeit in a different setting to this investigation) tended to involve sub-micron particles. Meanwhile, handling of the ‘dirty’ firearm did not result in transfers of similarly large particles and further study could explore the extent to which this is a repeatable observation.

With reference to the applicability of these findings, the results point to a number of possible implications for forensic protocol in an investigation involving GSR analysis. When collecting samples, it is desirable to sample, as soon as possible, as many surfaces and subjects that may have been involved in contact with the shooter or firearm as possible, thus preserving important information and arresting its spread via further transfers. This will enable the comparison of samples and potentially enable the reconstruction of transfers, while restricting the loss of important evidence. Automation of the detection and analysis process using SEM-EDX facilitates the analysis of these extra samples and can provide particle counts as well as sizes of the individual particles detected. These measures can provide useful information for reconstructing transfers. The importance of ensuring the accuracy of these measures is underlined, and accordingly, the need to manually verify and review the outputs of analysis is stressed. Moreover, when comparing GSR counts, for example, it is vital to maintain consistency in the analysis conditions and settings between analysis runs. The findings also emphasise the need to be aware that secondary transfers may continue to operate during arrest, suspect handling or firearm seizure – potentially a transfer from suspect to officer or from illicit firearm to officer could result in the interpretation of important evidence being complicated.

It is perhaps in the interpretation of GSR evidence that the findings have the greatest significance. The results demonstrate that the presence of GSR (particularly in small quantities) may not always indicate that a subject discharged a firearm, as the potential exists, particularly immediately after a firing, for particles to be transferred. This must be acknowledged when interpreting a sample recovered from a suspect. Indeed, without an awareness of secondary transfer mechanisms that can result in the transfer of GSR to an innocent individual or accomplice via contact with the shooter or the firearm, there is potential for misinterpretation and possibly misidentification of the shooter. Furthermore, the presence of a small number of particles that were acquired through a recent secondary transfer could, conceivably, be misinterpreted as being indicative of an earlier deposition from a firearm discharge to a shooter that has been subject to decay in the initial few hours following firing.[36] The importance of acknowledging the potential for secondary transfer and the need to gain further information regarding the timeframes involved are again underlined.

The findings from this study highlight the potential for GSR counts to assist in distinguishing the shooter from individuals who have acquired GSR through secondary transfer, and in corroborating/refuting claims of secondary transfer or contamination. It must be noted that the particle counts in this study represent an 'extreme' as, to capture the full extent of any transfer, samples were taken without a delay. However, given the numbers of particles detected, these findings suggest that after a (short) delay following transfer, detectable numbers of particles could be recovered from the surfaces. Clearly, the effects of persistence and decay will complicate the process of interpretation in casework, and this must be built into the reconstruction analysis. Establishing a time frame will be crucial in cases where a significant period has elapsed and additional experimental work that develops this study will be required to achieve this.

In terms of the particle size analysis, the results highlight that the presence of large particles (50–100+ μm) on a sample taken from a subject may not necessarily be indicative of that subject having fired the gun. Even large particles, it has been shown, can be transferred via a handshake and a full range of different sized particles can be recovered from both a shooter and an individual who has acquired GSR via a handshake. Analysis of the particle size data could be a valuable resource in the reconstruction of GSR transfers. For example, combined with elemental analysis, particle size analysis could assist in determining whether GSR recovered from two surfaces originated from the same source. Results suggest that further analysis of the dynamics of transfer and investigation of whether certain particles are more likely to transfer than others, are warranted. The time frame and decay of particles will need to be acknowledged, yet understanding which particles will be expected to have decayed and which will remain at a given point in time may make it possible, using particle size analysis, to distinguish a person who fired a gun some time ago and another who recently acquired a small quantity of GSR via secondary transfer.

It is necessary to emphasise the danger of extrapolating too far from the results of this study. As with any experimental study, the results generated here refer to a specific set of conditions but provide an insight into mechanisms that may be influential in real-world contexts and applicable to other scenarios. The findings provide an initial exploration of secondary transfers of GSR and indicate many avenues for further work, which would contribute to our understanding of these dynamics and to our ability to accurately reconstruct crime scenes. To provide a comprehensive understanding of the mechanisms involved, additional experimental runs using different firearm/ammunition combinations would be necessary, in addition to further work to establish the degree of tertiary transfer[23] that can occur. Transfers involving direct contacts could also be compared with the deposition that occurs when an individual is merely standing in the proximity of a firearm as it is being discharged. Finally, it will be important to establish how much material is left at the donor surface after a transfer, i.e. on the shooter after a handshake, to explore the potential for reconstructing transfer chains. Such work will assist in determining the probability that different mechanisms and activities (including firearm discharge, secondary transfers and being in the proximity of a firearm discharge) were responsible for the acquisition of GSR.

Conclusions

This study set out to establish, by means of an experimental approach and analysis using SEM-EDX, whether secondary transfers of GSR can occur in situations that mimic those encountered in casework. The investigation considered the extent of these transfers, as well as the implications they may pose for forensic investigations. The results provide a contribution to the body of literature on GSR dynamics by establishing that secondary transfers of GSR can take place in significant quantities, especially if contacts are made immediately after firing, from a shooter to a subject via a handshake and to a subject upon handling a discharged firearm. The amount of material transferred varies between contacts, but was found to be lower than that deposited on the shooter during firearm discharge. A full range of different sized particles may be transferred from the shooter to a subject via a handshake, including very large particles such as the particle measuring 102.46 μm, which was transferred from the shooter via a handshake during this investigation. Notably, such large particles were not recovered from the handler of a firearm. Further study would assist in understanding the extent to which this is a repeatable observation and a discriminatory tool in crime reconstruction. The implications of this study for a forensic investigation include the necessity to sample from as many subjects and surfaces as possible, to enable the reconstruction of the crime scene as accurately as possible. Meanwhile, an awareness of the possibility of secondary transfer having occurred is advised when attempting to reconstruct incidents and determine the provenance of GSR. The presence of GSR (especially in limited quantities) may not always indicate that an individual fired a gun and could instead be attributed to the handling of a firearm or contact with the shooter. However, when interpreting GSR in casework, the time between discharge and transfer, as well as the delay between transfer and collection and the effects of persistence will all need to be taken into account. The study presents the potential importance of analysing particle sizes. The sizes of particles recovered from a shooter and from a secondary contact may be very similar, and the presence of large particles must not be assumed to be necessarily indicative of firing a gun.

This study highlights the potential to further increase our understanding of the dynamics of GSR through experiments designed to maximise ecological validity, coupled with SEM-EDX analysis and automated detection software. This study establishes that secondary transfer mechanisms can operate in settings that mimic forensic contexts, providing a foundation for more in-depth investigation into the mechanisms of GSR secondary transfer and their interpretation. This, along with the results of this study, will inform firearm incident reconstruction and assist in improving the accuracy of interpretations of GSR presence which are presented in court.

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References

[1] R. Schumacher, M. Barth, D. Neimke, L. Niewöhner, in Scanning Microscopy 2010, (Eds: M. Postek, *et al.*), Proceedings of the SPIE, **2010**; *7729*, 772917.
[2] Z. Brozek-Mucha. *Z Zagadnien Nauk Sadowych* **2002**, *51*, 119.
[3] G. Cecchetto *et al. Int. J. Leg. Med.* **2011**, *125*, 2.
[4] Z. Brozek-Mucha, A. Jankowicz. *Forensic Sci. Int.* **2001**, *123*, 39.
[5] J. Lebiedzik, D. Johnson. *J. Forensic Sci.* **2002**, *47*(3), 493.
[6] J. Brazeau, R. Wong. *J. Forensic Sci.* **1997**, *42*(3), 424.
[7] M. Perdekamp *et al. Int. J. Legal Med.* **2011**, *125*(1), 67.
[8] B. Heard, Handbook of Firearms and Ballistics: Examining and Interpreting Forensic Evidence, Wiley, Chichister, **2008**.
[9] F. Romolo, P. Margot. *Forensic Sci. Int.* **2001**, *119*(2), 195.
[10] O. Dalby, D. Butler, J. Birkett. *J. Forensic Sci.* **2010**, *55*(4), 924.
[11] W. Tilman. *J. Forensic Sci.* **1987**, *32*(1), 62.
[12] N. Nag, P. Sinha. *Forensic Sci. Int.* **1992**, *56*(1), 1.
[13] J. S. Wallace, Chemical Analysis of Firearms, Ammunition, and Gunshot Residue, CRC Press, FL, **2008**.
[14] G. Wolten, R. Nesbitt, A. Calloway, G. Loper. *J. Forensic Sci.* **1979**, *24*(2), 421.
[15] C. Torre, G. Mattutino, V. Vasino, C. Robino. *J. Forensic Sci.* **2002**, *47*(3), 494.
[16] M. Grima, M. Butler, R. Hanson, A. Mohameden. *Sci. Justice* **2012**, *52*(1), 49.
[17] V. Matricardi, J. Kilty. *J. Forensic Sci.* **1977**, *22*(4), 725.
[18] R. White, A. Owens. *J. Forensic Sci.* **1987**, *32*(6), 1595.
[19] G. Jackson, R. Cook. *Forensic Sci. Int.* **1986**, *32*, 275.
[20] M. Grieve, J. Dunlop, P. Haddock. *Forensic Sci. Int.* **1989**, *40*, 167.
[21] B. Gaudette, A. Tessarolo. *J. Forensic Sci.* **1987**, *32*(5), 1241.
[22] R. Van Oorschot, M. Jones, *Nature* **June 1997**, *387*, 767.
[23] J. French *et al. Sci. Justice* **2012**, *52*(1), 33.
[24] S. Charles, N. Geusens. *Forensic Sci. Int.* **2012**, *216*(1–3), 78.
[25] D. Gialamas, E. Rhodes, L. Sugarman. *J. Forensic Sci.* **1995**, *40*(6), 1086.
[26] R. Berk, S. Rochowicz, M. Wong, M. Kopina. *J. Forensic Sci.* **2007**, *52*(4), 838.
[27] S. Basu, C. Boone, D. Denio, R. Miazga. *J. Forensic Sci.* **1997**, *42*(4), 571.
[28] E. Lindsay *et al. Can. Soc. Forensic Sci. J.* **2011**, *44*(3), 89.
[29] R. Morgan *et al. Sci. Justice* **2009**, *49*(4), 277.
[30] L. Reid *et al. J. Forensic Sci.* **2010**, *55*(3), 753.
[31] M. Rosenberg, C. Dockery. *Applied Spect.* **2008**, *62*, 11.
[32] L. Fojtášek, T. Kmjec. *Forensic Sci. Int.* **2005**, *153*(2–3), 132.
[33] J. Andrasko, A. Maehly. *J. Forensic Sci.* **1977**, *22*(2), 279.
[34] D. Northrop. *J. Forensic Sci.* **2001**, *46*(3), 560.
[35] J. Lebiedzik, D. Johnson. *J. Forensic Sci.* **2000**, *45*(1), 83.
[36] T. Jalanti, S. Henchoz, A. Gallusser, M. Bonfanti. *Sci. Justice* **1999**, *39*(1), 48.

