Gunshot Residue in a Non-Firearm Detainee Population

Award Number 2010-DN-BX-K222

William M. Davis, PhD

Harris County Institute of Forensic Sciences

Houston, TX 77054

This project was supported by Award No. 2010-DN-BX-K222, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

Abstract

Gunshot residue (GSR) analysis is a popular forensic technique used to determine whether a person or object have been in close proximity to fired weapon. This sub-discipline of trace evidence examines samples for the presence of characteristic primer particles that have specified morphologies and the presence of specific chemical elements (*i.e.* lead, barium and antimony (Pb/Ba/Sb)). Unfortunately, sampling surfaces of interest must be done in a relatively short timeframe in order to avoid the loss of evidence. Equally important is the avoidance of contamination. Studies have shown varying amounts of GSR in the police environment, the most being on surfaces within facilities occupied and operated by law enforcement. In an effort to ascertain the amount of GSR that may be finding its way onto unintended surfaces, we undertook a study of the hands of detainees being processed at the Harris County Jail, Pre-trial Services Division. These particular detainees were not charged with any offenses related to the discharge of a weapon. The use of these detainees was sanctioned by an institutional review board. Of the 175 samples obtained and tested during the grant period, not one characteristic GSR particle was captured. Coupling the results of this study and one in which no particles were found from 100 persons answering bench warrants in Bexar County, Texas gives an average of less than one particle in 275 hand samples. Considering the fact that a different study of random surfaces within the Chicago Police Department (N = 201) revealed a total of 56 particles, we arrive at a conclusion that these particles are not readily transferred to unintended surfaces. Applying the Poisson (counting) probability model to the current combination of findings ($\mu < 1/276 < 0.00362$), we report the probabilities that arise for the detection of the small numbers of GSR particles in this population. The results suggest that a best practice for GSR analysis could be a threshold of three characteristic Pb/Ba/Sb particles, as the presence of this number of

This project was supported by Award No. 2010-DN-BX-K222, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

particles is unlikely to be observed as the result of chance. A higher threshold lessens the probability further.

The scope of this project was expanded to examine the prospects of Direct Analysis in Real Time-Time of Flight (DART-TOF) mass spectrometry for the analysis of organic gunshot residues. Standard SEM stubs were used to ascertain the association between organic and inorganic residues. Initial attempts at observing pertinent analytes in unexploded powders proved to be successful, in that ethyl centralite was detected in pulverized powder samples. Samples collected from firearms examiners immediately after test firing weapons, and samples collected from the antechamber of the shooting tank provided no data that could be construed as a residue from the detonation of gunpowder. All of the samples were found to be positive for inorganic GSR.

This project was supported by Award No. 2010-DN-BX-K222, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

Table of Contents

This project was supported by Award No. 2010-DN-BX-K222, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

Executive Summary

Gunshot residue (GSR) analysis is a forensic sub-discipline in Trace Evidence. The forensic utility of GSR evidence is to provide information as to whether there is a primary association of a person or surface with the discharge of a weapon or subsequent handling of a discharged weapon. There are many factors that can affect the persistence of GSR on a given surface which include, but are not limited to: time between the event and sampling, activity (cleansing), and environment (weather). Additionally, defense counsels may use the fact that peace officers, who are licensed to carry and use firearms, as well as their places of employment are potential sources of contamination.

While GSR examiners around the world concur with certain premises (residues arising from the detonation of lead styphnate, barium nitrate, and antimony sulfide primers (Pb/Ba/Sb) are characteristic; and the presence of GSR does not necessarily indicate that a person has fired a weapon), there is not a general consensus as to what are the relevant background levels. At the FBI Laboratory's 2005 Gunshot Residue Symposium, the attendees reported minimum thresholds ranging from one to fifteen Pb/Ba/Sb particles, with a majority stating that one was a sufficient threshold.[1] This discrepancy leads to confusion in the interpretation of results. While the National Academies report of 2009, "Strengthening Forensic Science in the United States: A Path Forward," does not directly address GSR evidence, its recommendation that reporting be more uniform is key to this issue.[2] Furthermore, the interpretation of a particular result should be standardized.

Thresholds can be utilized to determine the statistical significance of a result when compared to a population of interest. If the average number of Pb/Ba/Sb particles that could be

This project was supported by Award No. 2010-DN-BX-K222, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

collected from the hands of the general population were known, then an analysis via the Poisson probability distribution function

$$P_n = \frac{\mu^n}{n!} e^{-\mu}$$

where μ is the average number of Pb/Ba/Sb particles within the population and n is a proposed threshold number of particles for declaring a positive result, can provide this statistical inference. The obvious problem is that the entire population cannot be evaluated; hence, a suitable sample is needed to formulate an estimate.

A study conducted by Berk, et al. focused primarily upon surfaces thought to be most commonly encountered by suspects in police custody (e.g. rear seats of patrol cars, interview rooms, lock-ups).[4] The investigation focused on surfaces in the Chicago Police Department. In this study a total of 201 surfaces were analyzed, and a total of 56 Pb/Ba/Sb particles were found. The results indicate that there is a significant amount of GSR in the police environment, a conclusion that may not be surprising. However, the question then becomes how much of this residue gets transferred to unintended surfaces.

Efforts to elucidate the presence of GSR in a population with no recent, direct exposure to a shooting event, but who do have routine contact with such an environment as described above, are available in the literature. Two studies of the prevalence of GSR in a sample of "non-shooting" populations focused upon police officers who had not fired their weapons for lengthy periods of time, up to 90 days.[5,6] A total of four Pb/Ba/Sb particles were found on the hands of 124 police officers in the combined studies. These results suggest that the transfer and subsequent retention of GSR is relatively unlikely. Another study of subjects appearing before magistrates after being in police custody yielded no Pb/Ba/Sb particles on the dominant hands of

This project was supported by Award No. 2010-DN-BX-K222, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

one hundred individuals.[7] The disparity in the results of these studies is the impetus for this work.

An additional 175 persons were sampled in this study. The subjects were detainees being processed at the Harris County Inmate Processing Center (IPC). Consent and sampling practices were carried out in the pre-trial services area of the IPC. The samples were subsequently analyzed by scanning electron microscopy/energy dispersive x-ray spectroscopy (SEM/EDX). No characteristic GSR particles were found on the carbon-tape collection devices.

Since no positive observations were made, the discussion should be framed in terms of inequalities. A combined average of the results of this study and those of reference 7 will be used. Conservatively, if one additional measurement had resulted in the observation of a single particle, then $\mu \leq 0.00362$. The Poisson distribution function for this mean results in the inference that more than 99.96 percent of the uninvolved population should yield zero observed characteristic GSR particles. If employing a threshold of three particles (it should be noted that the Scientific Working Group on Gunshot Residue (SWGGSR) does not offer guidance on this matter for primary association), we would see the odds of finding this number of characteristic particles on an uninvolved person at less than approximately 1:100,000,000. None of these scenarios includes the complicated time dependence of the distribution of GSR on a person.

Detection of Organic Residue DART-TOF

The scope of this project to detect GSR on the hands of detainees was expanded to include the detection of the organic components of gunshot residues using ambient-pressure ionization mass spectrometry, specifically DART-TOF. The goal was to examine all of the stubs

This project was supported by Award No. 2010-DN-BX-K222, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

collected in the detainee portion of this project using instrumental parameters optimized in the examination of known, positive GSR samples.

Organic residues of importance would be those left behind as unexpended portions of the powder charge (i.e. nitroglycerine or pentaerythritol tetranitrate (PETN) or stabilizers such as ethyl centralite (EC)). Instrumental parameters were determined based upon the successful detection of EC in pulverized powder charges from both Remington and Winchester ammunitions. It should be noted that EC has been detected using electrospray ionization mass spectrometry[8]. Efforts at detecting any organic components on the hands of firearms examiners or samples from other surfaces known to be positive for inorganic GSR were unsuccessful. Reasons for this lack of detection could be, but are certainly not limited to: low sensitivity of the DART-TOF instrument to these analytes, or a far lower level of discharge from breeches away from the barrel axis. Further investigation may be necessary.

This project was supported by Award No. 2010-DN-BX-K222, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

Introduction

Gunshot residue (GSR) analysis is a forensic sub-discipline in Trace Evidence. The forensic utility of GSR evidence is to provide information as to whether there is a primary association of a person or surface with the discharge of a weapon or subsequent handling of a discharged weapon. There are many factors that can affect the persistence of GSR on a given surface which include, but are not limited to: time between the event and sampling, activity (cleansing), and environment (weather). Additionally, defense counsels may use the fact that peace officers, who are licensed to carry and use firearms, as well as their places of employment are potential sources of contamination.

While GSR examiners around the world concur with certain premises (residues arising from the detonation of lead styphnate, barium nitrate, and antimony sulfide primers (Pb/Ba/Sb) are characteristic; and the presence of GSR does not necessarily indicate that a person has fired a weapon), there is not a general consensus as to what are relevant background levels. At the 2005 FBI Laboratory's Gunshot Residue Symposium the attendees reported minimum thresholds ranging from one to fifteen Pb/Ba/Sb particles, with a majority stating that one was a sufficient threshold.[1] Furthermore, the Scientific Working Group on Gunshot Residue (SWGGSR) offers no suggestions in this matter.[2] This discrepancy leads to confusion in the interpretation of the results. While the National Academies report of 2009, "Strengthening Forensic Science in the United States: A Path Forward," does not directly address GSR evidence, its recommendation that reporting be more uniform is key to this issue.[3] Furthermore, the interpretation of a particular result should be standardized.

This project was supported by Award No. 2010-DN-BX-K222, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

Thresholds can be utilized to determine the statistical significance of a result when compared to a population of interest. If the average number of Pb/Ba/Sb particles that could be collected from the hands of the general population were known, then an analysis via the Poisson probability distribution function

$$P_n = \frac{\mu^n}{n!} e^{-\mu}$$

where μ is the average number of Pb/Ba/Sb particles within the population and n is a proposed threshold number of particles for declaring a positive result, can provide this statistical inference. The obvious problem is that the entire population cannot be evaluated; hence, a suitable sample is needed to formulate an estimate.

A study conducted by Berk, et al. focused primarily upon surfaces thought to be most commonly encountered by suspects in police custody (e.g. rear seats of patrol cars, interview rooms, lock-ups).[4] The investigation focused on surfaces in the Chicago Police Department. In this study a total of 201 surfaces were analyzed and a total of 56 Pb/Ba/Sb particles were found. These results indicate that there is a significant amount of GSR in the police environment, a conclusion that is not too surprising. However, the question now becomes how much of this residue gets transferred to unintended surfaces.

Two such studies of the prevalence of GSR in sample "non-shooting" populations focused upon police officers that had not fired their weapons for lengthy periods of time, up to 90 days.[5,6] The officers involved were reporting for duty as usual; hence, they all had contact with their environment. A total of four Pb/Ba/Sb particles were found on the hands of 124 police officers in the combined studies. Applying the Poisson probability function with this mean, μ =

This project was supported by Award No. 2010-DN-BX-K222, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

0.0322, the cumulative probabilities of observing up to and including the threshold number of particles (ranging from 1 to 15) within this population are presented in Table 1. These probabilities can be contrasted with those of the Chicago PD study ($\mu = 0.279$) in Table 2.

The minimum threshold listed in Table 1 indicates that finding one Pb/Ba/Sb particle is not as rare an event as anticipated. But given that 99.94 percent of this population would show either zero or one such particle at any given time, the odds of finding one are quite small, but significant. In contrast, for the fifteen particle threshold, where the entire population is expected to have between zero and fifteen particles, the odds of finding this many particles are infinitesimally small. In fact, the latter situation is essentially unchanged when the threshold is reduced to ten Pb/Ba/Sb particles. Accordingly, an ideal threshold would be somewhere between these extremes; therefore, these studies are a good reflection of the general population.

These results indicate that transfer of GSR in the environment to police officers is likely to be limited. Certain effects cannot be ruled out in this paucity of residue. Good hygienic practices, such as frequent hand washing, could mask the true amount being transferred. Regardless, the major question remains whether the police are a source of contamination to others.

A study of subjects appearing before magistrates after being in police custody yielded no Pb/Ba/Sb particles on the dominant hands of one hundred individuals.[7] The lack of residue in that study served as the impetus for the current effort.

Organic Residues

There has been activity in recent years in the detection of organic GSR. Techniques ranging from ambient pressure mass spectrometry[8], to gas chromatography with nitrogen-

This project was supported by Award No. 2010-DN-BX-K222, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

phosphorus detection[9] and infra-red techniques[10,12] have been explored. One rationale behind these explorations is an anticipated move away from ammunition containing high atomic number elemental components or traditional antimony/barium/lead based primers.

Methods

Sampling

Human subjects were sampled for GSR according to a plan approved by an independent Institutional Review Board (IRB). The plan called for gathering informed consent in as private setting as possible. All samples were collected from detainees being processed at the Harris County Jail. The area chosen for interviews and sampling is known as pre-trial services. In this part of the Inmate Processing Center (IPC) detainees are assessed for the purposes of bond assignments prior to probable cause hearings. The pre-trial services area is composed of a general gathering area and four interview booths with a steel screen separating interviewer and interviewee. A two inch opening between the counter-top and bottom of the screen allows for the passage of paperwork. One of these booths was chosen for consent consultation and GSR sampling. Sampling was done in the first two hours of the day shift (8:00am-10:00 am) on Tuesdays and Wednesdays. These times were chosen so as to incur minimum disruption to the normal conduction of business by pre-trial services staff. Access to the area was granted by both the Harris County Sheriff's Office and the Harris County Pre-Trial Services. Per a post-award agreement with the former, only the principal investigator (PI) was given authorization for access.

Potential donors were provided the name and employer of the PI, informed of the purpose of the study, and guaranteed that personal and biometric information was not being recorded. Additionally, potential participants were told that no genetic testing of the samples would be

This project was supported by Award No. 2010-DN-BX-K222, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

performed. Per the sampling design, no demographics were gathered. Over the course of sampling, a participation rate of approximately 70% was noted.

Samples were collected on carbon adhesive devices (TriTech Forensics). One device (pre-numbered, but randomly selected) was used to collect particles from the anterior and posterior of both hands of the participants. A total of 175 samples were collected between April, 2012 and December, 2012.

Particle Analysis

A fine layer of gold was applied to each sample prior to particle analysis. The coating was carried out using a sputter coater (EMS model 550). Samples were loaded onto a scanning electron microscope (SEM) (ASPEX Corp., LLC, model PSEM-II). In addition to the survey samples, one sample of the examiner's hands was analyzed as a negative control, and one known GSR sample and one Cu metal standard were loaded onto sample holders. All samples were analyzed using an excitation energy of 25kV and backscatter electron detection, using the Automated Feature Analysis (AFA) package provided by ASPEX, LLC with parameters optimized for GSR. Energy dispersive x-ray (EDX) data were obtained with an E2V silicon drift detector.

Organic Residues

Mass spectral data were collected using a JEOL DART-TOF mass spectrometer operating in both positive and negative modes. Instrument parameters are as in reference 12. All samples were collected on standard SEM GSR kits, *vide supra*. A standard mix of explosives was used as purchased from Cerilliant. Pulverized gun powders were taken directly from Remington and Winchester center-fire ammunition. Samples were collected from the faces and

This project was supported by Award No. 2010-DN-BX-K222, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

hands of firearms examiners within minutes of test firing semi-automatic pistols. Samples were also collected from the interior of the shooting tank region, where expended cartridge cases are collected.

Results

For the 175 samples collected and analyzed for this study, a total of 72,195 particles were either characterized or confirmed. Not one particle was detected that would be considered characteristic of gunshot residue. Of those particles that are considered consistent with GSR and binary in elemental composition, only 16 Pb/Sb-containing particles were noted. Single element particles were more numerous, with 218 Sb, 198 Pb and 100 Ba-containing particles. Even more numerous were particles attributed to lighter flint (a mixture of iron and lanthanide elements). The latter had an occurrence of well over 5,000 particles.

Organic Residues

Detection of components from the standard explosive mixture were disappointing. None of the components were detected with any reproducibility in either positive or negative mode. For pulverized gun powders, ethyl centralite was observed in both of the samples used. Samples taken from the faces and hands of firearms examiners after test firing weapons proved to show no detectable analytes of interest. Samples taken from the interior of the shooting tank yielded the same results.

Conclusions

The results of this study and that of the Bexar County (TX) bench warrant study[7] strongly suggest that GSR is not likely to be transferred from police officers or their restraining devices in the routine course of business. Less than one particle observed per 275 persons gives an average

observation rate, μ, of less than 0.0036. Poisson statistics based upon this average are given in Table 3. Given these statistics it can be inferred that greater than 99.6 percent of uninvolved person would be tested with a result of no GSR found. Additionally, we arrive at a probability on the order of 1:100,000,000 of finding three characteristic particles on an uninvolved person.

Organic Residues

The failure to detect the organic analytes of interest was certainly an alarming result in this study. Plausible explanations exist, but must be tested. These include:

1. DART-TOF may not be sensitive enough to detect these analytes in trace quantities. This is not likely, as the technique has successfully detected traces of TNT on clothing (according to JEOL product literature).
2. The organic residues do not exit the non-muzzle breeches in sufficient quantities. This is somewhat plausible in that other published studies[8-11] make no mention of these side-discharged residues. These studies focus on unexpended powders that discharge through the muzzle. In the present work, samples downrange from the test fires were not collected. This is an area for further investigation.
3. Instrumental parameters were not suitable for the types of analytes of interest. Again, a plausible possibility, but given the detection of ethyl centralite in the unexpended pulverized gun powders, unlikely, at least for ethyl centralite.

This project was supported by Award No. 2010-DN-BX-K222, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

Tables

Table 1. Poisson Probabilities of Various GSR Thresholds for μ = 0.0322 (police officers)

Threshold, n	Poisson Probability (Cumulative)[a] μ = 0.0322	Odds of observation[b]
1	3N490	~ 1 : 31
2	5N454	~ 1 : 1.98 x 10^3
3	7N506	~ 1 : 1 .84 x 10^5
5	11N848	~ 1 : 3.55 x 10^9
10	1	Vanishingly small
15	1	Vanishingly small

Table 2. Poisson Probabilities of Various GSR Thresholds for μ = 0.279 (police environment surfaces)

Threshold, n	Poisson Probability (Cumulative)[a] μ = 0.279	Odds of observation[b]
1	1N678	~ 1 : 3.74
2	2N707	~ 1 : 33
3	3N799	~ 1 : 365
5	6N488	~ 1 : 9.44 x 10^4
10	12N411	~ 1 : 4.77 x 10^{10}
15	1	Vanishingly small

This project was supported by Award No. 2010-DN-BX-K222, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

Table 3. Poisson Probabilities of Various GSR Thresholds for μ < 0.0036 (This study and that of Ref. 6)

Threshold, n	Poisson Probability (Cumulative)[a] μ < 0.0036	Odds of observation[b]
1	> 2N641	< 1 : 276
2	> 5N354	$< 1 : 1.55 \times 10^5$
3	> 8N225	$< 1 : 1.29 \times 10^8$
5	> 14N500	$< 1 : 1.99 \times 10^{14}$
10	1	Vanishingly small
15	1	Vanishingly small

Notes for all tables

[a] The cumulative value is the sum of all probabilities up to and including the threshold. The notation used for this value is based upon the number of leading nines in the probability, for example 0.999490 is represented as 3N490. [b]Individual (non-cumulative) probabilities listed as $[(1-P_n)/P_n)]$, the odds of finding this value in the population.

This project was supported by Award No. 2010-DN-BX-K222, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

References

1. Wright, D.M and Trimpe M. A., "Summary of the FBI Laboratory's Gunshot Residue Symposium", *For. Sci. Comm.*, **2006**, *8*, http://www.fbi.gov/about-us/lab/forensic-science-communications/fsc/july2006/index.htm/research/2006_07_research01.htm

2. "Guide for Primer Gunshot Residue Analysis by Scanning Electron Microscopy/Energy Dispersive X-Ray Spectrometry 11-29-11", http://swggsr.org/FINAL%20GUIDE11-29-11.pdf, Scientific Working Group on Gunshot Residue, 2011.

3. "Strengthening Forensic Science in the United States: A Path Forward", The National Academies Press, Washington DC, 2009.

4. Berk, R. E., et al., *J. Forensic Sci.*, **2007**, *52*, 838-841

5. Gialamas, D. M., et al., *J. Forensic Sci.* **1995**, *40*, 1086-1089.

6. Cardinetti, et al., *Scanning*, **2006**, *28*, pp. 142-147.

7. Martinez , M. V. Bexar County Criminal Investigation Laboratory, and Garcia J. D. U.S. Army Crime Laboratory, personal communication at the FBI Laboratory GSR Symposium, May 31–June 3, 2005.

8. Morelato, M., *et al.*, *For. Sci. Int*, **2012**, *217*, pp. 101-106.

9. Lopez-Lopez, M., Delgado, J. J., and Garcia-Ruiz, C., *Anal. Chem*, **2012**, *84*, pp. 3582-3585.

10. Bueno, J., Sikirzhytski, V., and Lednev, I. K., *Anal. Chem.*, **2012**, *84*, pp. 4334-4339.

11. Burleson, G. L., *et al.*, *J. Chrom. A*, **2009,** *22*, pp. 4579-4683.

12. Samms, W. C., *et al.*, *J. For. Sci.*, **2011,** *54*, pp. 993-998.

This project was supported by Award No. 2010-DN-BX-K222, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

Dissemination of Research Findings

The results of this study were presented at the 2014 AAFS National Scientific Meeting in Seattle, WA. A manuscript will be submitted for publication in a refereed journal whose editorial preferences are in the Forensic Sciences.