J Forensic Sci, Apr. 1977, Vol. 22, No. 2

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Detection of Gunshot Residues on the Hands by Trace Element Analysis

In the investigation of cases involving shooting, one of the important links in the chain of proof is evidence that a person fired the gun or was in some way connected with the firing. This has long been attempted by the detection of gunshot residues on the hands of the suspect. One of the early methods was the familiar "paraffin cast" or "dermal nitrate" technique. Warm paraffin was poured on the hands; the paraffin, upon cooling, formed a cast. The cast was then peeled off and the adhering powder residue was detected by means of a color reaction of the nitrate with diphenylamine reagent. Although the paraffin cast was accepted as a method of lifting the residues, the diphenylamine reaction proved to be unsatisfactory in that numerous false positives were encountered. Any substance containing nitrate, such as cigarette ash and urine, gave a positive reaction. The method was therefore abandoned as a means of detecting gunshot residues [*1*].

In 1959, Harrison and Gilroy [*2*] observed that when a person discharges a firearm inorganic elements such as lead, barium, and antimony are deposited on the hands. The detection of these elements, usually present in trace amounts, formed the basis for determining whether or not the person had recently fired a weapon. Harrison and Gilroy used color spot tests for this purpose. It was soon realized that qualitative spot tests were not adequate since "normal" hands, that is, hands of persons who had not fired a gun, contained the same elements, albeit in much smaller amounts. Although the basic concept of Harrison and Gilroy had merit, it was apparent that a quantitative method for determining trace elements on the hands was needed.

Schlesinger et al [*3*] reported data on the amounts of antimony and barium on the hands of persons of differing occupations who had not fired or handled a gun, termed "hand blanks," and also on those who had fired a handgun. Several types of handguns were studied. The study dealt mainly with laboratory test shots and not with conditions encountered in actual case situations. Neutron activation analysis was used for the detection of antimony and barium.

Since 1970, a number of workers [*4-10*] have studied various aspects of the deposition and detection of gunshot residues. Different analytical techniques, such as atomic absorption [*10*], X-ray fluorescence [*11*], and photoluminescence [*12*] have been used. At present, the most common analytical techniques used are neutron activation analysis for the detection of antimony and barium, and atomic absorption spectrophotometry for the detection of lead, antimony, and barium.

Since 1968, this laboratory has been attempting to develop a technique for application

Received for publication 15 July 1976; revised manuscript received 7 Sept. 1976; accepted for publication 8 Sept. 1976.

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in actual cases. Although the literature is extensive, it deals mostly with controlled laboratory conditions. Our earlier work indicated that under the circumstances of actual case incidents, the conditions and therefore the results with respect to gunshot residue deposition are widely different. The various conditions such as the distribution of deposits, the length of time during which residue can be expected to remain, and factors other than firing (struggle or handling the fired gun or cartridge cases) must be restudied under these circumstances. The literature also deals mostly with handguns. Studies on rifles and shotguns were necessary. It was apparent that, for successful application, the entire procedure, from the sampling technique to the interpretation of results, had to be developed as a total system in order to effectively control it.

The results of such a study and a development effort of nearly 8 years are reported in this paper. More than 1500 test shots have been fired, and a number of factors encountered in case situations have been studied. Fifty-seven weapons, including pistols, revolvers, rifles, and shotguns, have been tested and a critical discussion of the interpretation of the results has been outlined.

Background

Concept

It is now well established that significant amounts of lead, antimony, and barium are deposited on the hands upon firing a handgun. The actual amounts reported [*4,9,13*] vary with different laboratories. Some of this variation is due to inherent variation of residue deposition from shot to shot even when the same gun is used; some is due to different sampling techniques.

Collection Methods

The collection of gunshot residue from the hands of a suspect is a critical part of the system. Considerable effort has been directed by many workers toward the development of satisfactory practical sampling methods. Although several procedures are in use, all of them must meet certain basic requirements. Since the sample is generally collected in the field by the investigator, the method must be simple enough to be understood and performed by him. It should be fast and provide minimal opportunity for contamination. It should be inexpensive and the apparatus or the kit should be easily prepared and tested for quality, specifically, low background levels of trace elements. Since quantitative results are required, the method should quantitatively and reproducibly remove the residue from the hand. Several types of kits are in use in different laboratories.

Paraffin and Other Film Lifts—A film or cast is made on the hand and gunshot residue adheres to the film which is then lifted and analyzed for trace elements. The materials used include paraffin [*3*], collodion [*14*], and cellulose acetate [*6*]. These methods are inconvenient for routine use in the field and require several minutes to complete, thereby providing opportunities for external contamination. When neutron activation analysis is used as the analytical technique, a single lift occupies most of the irradiation capsule and adds considerably to the cost. The film lift techniques, therefore, are generally not popular with forensic laboratories which handle a large number of cases.

Swabs—A cotton swab on the tip of a plastic or wooden stick moistened with hydrochloric or nitric acid is used to swab the residue from the hands. In addition to cotton swabs, swabs of filter paper disks [*4*] moistened with acid are also being used. This method is simple, the kit is inexpensive, and it is easy to train the investigator in its use. However, our earlier experiments showed [*15*] that it may not be extremely efficient in removing the residue and the amount removed may differ with the pressure applied.

While a batch of cotton swabs has been found by analysis of random samples to be free of contamination, the condition of individual swabs may still be subject to question in court proceedings. Nevertheless, the disadvantages are not serious and the method is used in many laboratories [*16,17*].

Washing—A more recent method for sample collection is simply washing the suspect's hand with approximately 50 ml of water [*12*] or dilute nitric acid [*9*]. The washing can be done with a plastic squeeze bottle or by dipping the hand into a bag containing the liquid. The residue appears to be mechanically removed by the water or dilute nitric acid which are comparable in effect (removal of more than 80% and 95%, respectively). Nitric acid aids in getting the trace elements into solution for further chemical analysis. The advantage of this method is its simplicity. It takes less than a minute to complete and therefore provides little opportunity for contamination. Large volumes of the liquid can be prepared, checked for background contamination, and used to prepare a large number of kits. By using reagent-grade nitric acid and deionized water the background levels are found to be insignificant. Since the entire hand is washed, this method does not provide distribution data (the location of the residue on the hand). This is not a great loss in case work, as discussed later.

Tape Lift—A recent addition to sample collection techniques is the use of adhesive tape [*18*] to lift the residue from the hand. The method is simple and applicable to field use. It has undergone limited evaluation and further work by a number of laboratories needs to be done before it is widely accepted as a routine technique.

Efficiency of Residue Collection Methods.

Several of the residue collection methods were tested [*15*] in this laboratory for ease of operation and efficiency. After applying the technique once, it was reapplied to the same hand to determine whether the second attempt removed any remaining residue. Our results showed that with the film lift and swabbing techniques, 5 to 15% of the amount of residue found on the first sampling could be picked up on the second application. With the washing method, a negligible amount was found on the second attempt.

The choice of the sample collection method must be made by each laboratory. No one method appears to be superior to another in all respects, and factors such as availability of kits, compatibility of samples with subsequent analytical techniques used, and user preference have to be considered.

This laboratory, after consultation with the police officers in the region, selected the washing method. Accordingly, kits with two clean bottles containing 50 ml of 5% nitric acid each, two clean plastic bags for the dipping, and instructions were supplied to investigators (Figs. 1 and 2).

Analytical Techniques

The analytical technique used must be capable of determining the trace elements quantitatively at microgram to nanogram levels. Traditionally, neutron activation analysis has been used to detect antimony and barium, since most of the initial background data have been obtained by that method. In recent years, flameless atomic absorption spectrophotometry has been used [*10*]. Lead can also be determined by this technique, whereas neutron activation analysis cannot detect lead conveniently.

While several other techniques have been attempted, these two are by far the most commonly used. Neutron activation analysis has a longer case turn-around time than

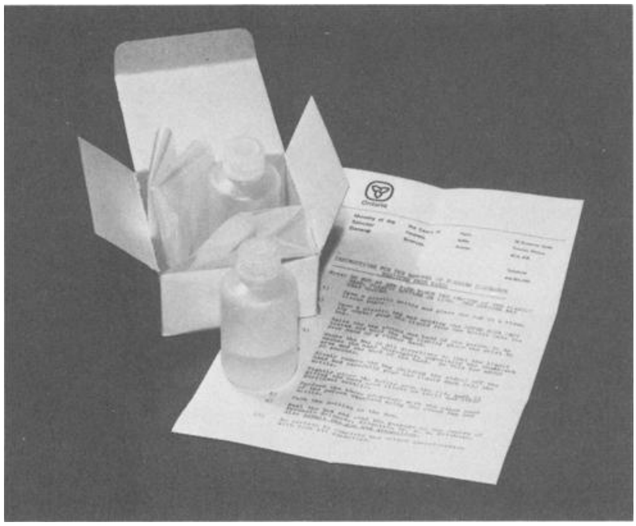

FIG. 1—*The gunshot residue kit.*

FIG. 2—*The hand being washed.*

atomic absorption since irradiation and radiochemical separations are involved. Neutron activation is not subject to contamination after the sample is irradiated, whereas atomic absorption is liable to contamination at any stage. Any contamination in the 20 to 50-μl analyte would lead to serious errors since the result is multiplied by several factors in calculating the total amount of trace element in the entire sample. Therefore extreme precautions have to be taken in handling the samples, and several aliquots must be analyzed to ensure that the absorption signal is real and not an artifact. When a graphite furnace atomizer is used the barium carbide formation often leads to poor accuracy and precision of the barium signal. Neutron activation analysis uses solid samples or small volumes of liquid, whereas atomic absorption analysis uses liquid samples. Neutron activation analysis is capable of simultaneous multielement analysis. Atomic absorption at present, with the commercially available equipment, is not capable of simultaneous multielement analysis.

Experience and skill are necessary with both techniques. The choice of the method, therefore, depends on the availability of equipment and experienced personnel.

Experimental Procedures

The analytical procedure used in this laboratory has been described elsewhere [*9*] and involves concentrating the hand washings to a small volume by freeze drying. A part of this is analyzed for lead by atomic absorption spectrophotometry while the other part is taken to dryness by freeze drying. This second part is irradiated in a nuclear reactor for 2 h in a thermal neutron flux of approximately 10^{13} n/cm$^2 \cdot$s. The irradiated sample is taken up in 1*M* nitric acid. A portion of it is allowed to decay until the interfering ^{24}Na and other radioactivities have decayed and the ^{122}Sb peak is clearly seen. The other portion is used to precipitate barium as the sulfate and the ^{139}Ba is counted. The chemical yield is approximately 97% for barium and 100% for antimony since no radiochemistry is done in the latter case. The amounts of antimony and barium are estimated by using suitable standards.

The equipment used for the radioactivity measurement is a Princeton Gamma-Tech Ge(Li) detector (35 cm^3), and the counting system is a Tracor Northern TN-11 system which uses a PDP 11 computer. The atomic absorption spectrophotometer used is an Instrument Laboratory Model IL 255 with a three-slot Boling burner. The lead is estimated using an air-acetylene flame.

Results and Discussion

Residue from Different Weapons

General—In Ontario, cases involving longarms (rifles and shotguns) are in the majority. This is the reverse of experience of laboratories in the United States where most shooting cases involve handguns. During the past 5 years, 57 different guns have been test fired in this laboratory to obtain basic data about the amounts of trace elements deposited from various handguns and longarms. The results are given in Table 1. In general, longarms deposit much less residue than handguns.

Handguns—Handguns are known to deposit more residue on the firing hand compared to the nonfiring hand [*3,4,9*]. This is not surprising since there is an opportunity for gases to escape at the breach end of handguns. Generally, in the same type of weapon, the larger the caliber, the larger the amount of residue deposited.

Longarms—In the case of longarms generally, with the exception of semiautomatics, the breach is closed during the firing and very little opportunity exists for gases to escape. Whatever escape takes place happens because of leakages in the particular gun. Residues may still be deposited on the hands of the firer but in much smaller amounts than with handguns. The term "nonfiring hand" is not strictly correct in discussing longarms since both hands are used. For this discussion, the firing hand is defined as the one that pulls the trigger and the nonfiring hand is the one which holds the barrel.

The action of the weapon is an important factor (Table 2). In single-shot, bolt-action rifles, there is no ready means of escape at the breach for the residue. Therefore, the residue deposited on the firing hand is small. The amount of deposit found on the other hand is also small since in normal shooting the hand is some distance from the muzzle (Table 2, Tests 1 to 3). In semiautomatic weapons the breach is open momentarily, immediately after firing while the spent shell is ejected. In these instances a somewhat larger amount of some of the trace elements may be deposited on the trigger hand

(Table 2, Test 10). Among the .22 rifles studied, the prewar German model Dreyse produced the maximum amount of residue (Table 2, Test 7). This gun has what is termed a "trap door" action and a large area at the breach is open during the ejection.

Another important factor in the case of longarms is the barrel length. It is known that gunshot residue comes from the muzzle in large amounts. The shorter the barrel, the closer the nonfiring hand is to the muzzle. Sawed-off rifles therefore may deposit, considering only the nonfiring hand, a larger amount of residue than the full-length weapon (Table 3). As the barrel length is shorter, a larger amount of residue is noticeable on the firing hand as well.

Case Situation—The results reported above are all derived from experiments done under laboratory conditions where the subject fired one shot and the samples were taken immediately after. While the data thus obtained is of value in the basic understanding of the technique, clearly the situations encountered in case work are vastly different. For example, when a person commits suicide with a gun, the gun may be held with both hands; either of the hands may be close to the muzzle and hence may receive residue from the muzzle blast. In hold-up and homicide incidents, the situation is more complex. The gun is loaded, single or multiple shots are fired, and sometimes the spent cartridge cases are handled in collecting and disposing of the evidence. All these acts deposit more residue than a single firing in a clean laboratory situation. Hence, in actual cases the levels of trace elements found on the hands are often much higher than in laboratory test findings (Table 4).

A study of 29 suicides involving several types of longarms showed amounts of 10 to 417 μg for lead, 0.03 to 9 μg for barium, and 0.05 to 3.93 μg for antimony. The amounts were comparable on both hands. A few of the actual case results are given in Table 4 for illustration. The values were spread over the range and no particular level occurred with maximum frequency. Generally, the levels of one or more trace elements are well above those found in the laboratory test firings of similar weapons (Table 1). Cowan et al [*13*] reported a study of 30 cases of suicides, accidents, and homicides using handguns. In that report, compared to barium levels of 0.18 to 1.44 μg obtained in laboratory shots, 18 of the 30 cases had amounts above 1.44 μg. Similarly, in the case of antimony, compared to laboratory shot levels of 0.09 to 0.44 μg with an average of 0.2 μg, 21 of 30 cases had levels above 0.44 μg. Similar results were reported by Cornelius [*4*].

Similarly, in simulated homicide cases in which the subjects loaded, fired, and then unloaded the cartridge cases, higher amounts of trace elements (Table 5) were found than those of laboratory test shots [*9*]. Similar results were reported by Cowan et al [*13*] where 12 subjects loaded and fired six shots each. The amounts of barium found on the firing hand varied from 0.48 to 25.5 μg, while antimony varied from 0.47 to 17.4 μg.

The amount of trace elements generally encountered in case work is well above those from laboratory test firings and there is little overlap with handblank levels [*9*], even the higher handblanks observed with certain types of occupations such as metal workers [*4*]. Thus, the absolute amounts themselves, in most instances, clearly indicate gunshot residue. Application of elaborate statistical methods developed [*3*] for distinguishing the residue in borderline cases where there is overlap with handblanks is therefore less important in actual cases and usually unnecessary.

When comparing trace element amounts in case samples, it is therefore of value to simulate the reported incident as closely as possible. To compare clean laboratory test shot results with case results without taking the above factors into consideration may be irrelevant and erroneous.

Distribution of Residue

One Hand Versus Other Hand—It is known that, in general, handguns deposite more

TABLE 1—*Trace elements deposited on the hands of general laboratory or other staff members who fired a gun. The hands were washed before the firing, which was done with the right hand.*

Test	Type of Weapon	Different Types, *n*	Tests, *n*	Ammunition	Hand	Range of Amounts Deposited, μg: Lead	Antimony	Barium
1	.38 revolver	6	300	various	right	13 to 326	0.35 to 5.9	0.19 to 1.40
					left	<10 to 110	<0.05 to 0.5	0.05 to 0.45
2	.22 revolver	1	10	Dominion	right	3.8 to 10.5	0.01 to 0.02	0.02 to 0.2
					left	0.94 to 9.9	0.005 to 0.02	0.02 to 0.08
3	.32 revolver	1	2	Dominion	right	54 to 94	1.5 to 3.3	0.98 to 1.21
					left	50 to 52	0.53 to 1.29	0.29 to 1.19
4	.45 pistol	2	10	Dominion	right	23 to 66	0.12 to 0.42	0.32 to 16.0
					left	3.6 to 30	0.01 to 0.35	0.06 to 0.29
5	.22 pistol	4	10	Dominion	right	11 to 24	0.04 to 0.29	0.3 to 4.0
					left	1.1 to 18	0.02 to 0.27	0.04 to 3.0
6	.32 pistol	2	2	Dominion	right	4.9 to 57	1.8 to 2.4	3.3 to 16.4
					left	3.7 to 44	0.86 to 2.0	1.3 to 5.4
7	7.65-mm pistol	1	2	Dominion	right	9 to 19	ND[a]	1.69 to 6.2
					left	7 to 10.0	ND	1.48 to 3.2
8	.22 rifle, bolt action	13	39	various	right	9 to 129	0.03 to 0.78	0.01 to 5.3
					left	6 to 37	0.03 to 0.73	0.01 to 4.2
9	.22 rifle, repeater	3	7	various	right	8 to 90	0.5 to 1.6	0.13 to 0.4
					left	8 to 75	0.5 to 1.4	0.07 to 0.3
10	.22 rifle, semi-automatic	6	34	various	right	4 to 128	0.02 to 2.0	0.01 to 2.6
					left	3 to 56	0.01 to 2.6	0.4 to 1.0
11	.22 rifle, sawed off, blowback	1	3	Imperial	right	75 to 150	6.6 to 9.3	0.74 to 4.2
					left	100 to 140	4.8 to 10.3	0.75 to 3.6
12	.22 rifle, single shot, trap door	1	3	CIL	right	10 to 100	0.77 to 4.64	0.79 to 8.8
					left	14 to 39	0.3 to 1.73	0.17 to 1.4
13	.303 rifle, bolt action	4	7	various	right	18 to 65	0.07 to 0.93	0.4 to 1.2
					left	21 to 29	0.05 to 1.34	0.1 to 0.9
14	30-06 rifle, bolt action	1	5	CIL	right	5 to 12.7	0.08 to 0.29	0.005 to 0.05
					left	1.2 to 11	0.23 to 0.6	0.02 to 0.05
15	.308 rifle, semi-automatic	1	5	Dominion	right	6 to 11.2	0.04 to 0.06	0.06 to 0.6
					left	4.9 to 7.7	0.04 to 0.05	0.01 to 0.3

16	.300 rifle	1	1	CIL	right	16 ...	0.17 ...	0.77 ...
					left	13 ...	0.22 ...	0.58 ...
17	30-30 rifle, lever action	2	6	various	right	13 to 50	0.08 to 0.65	0.1 to 0.15
					left	12 to 36	0.04 to 0.65	0.08 to 0.15
18	30-30 rifle, carbine, lever action	1	1	Dominion	right	14 ...	0.21 ...	0.95 ...
					left	18 ...	0.40 ...	1.14 ...
19	12-gage shotgun, single shot	1	3	Dominion	right	11 to 58	1.0 to 2.75	0.24 to 0.3
					left	9 to 35	1.3 to 1.4	0.19 to 0.3
20	12-gage shotgun, pump action	2	15	various	right	4 to 36	0.02 to 0.24	0.01 to 0.3
					left	5 to 31	0.01 to 0.15	0.02 to 0.2
21	16-gage shotgun, pump action	1	4	Winchester	right	25 to 84	0.13 to 0.24	0.19 to 0.76
					left	24 to 58	0.19 to 0.35	0.17 to 0.39
22	16-gage shotgun, semiautomatic	1	1	CIL	right	16 ...	ND	1.29 ...
					left	13 ...	ND	0.85 ...
23	20-gage shotgun, single shot	1	1	CIL	right	20 ...	ND	0.96 ...
					left	37 ...	ND	0.62 ...

[a] ND = not determined because of experimental difficulties.

TABLE 2—*Trace elements found on hands from longarms of different actions. The ammunition used was manufactured by Dominion. The right hand was used to pull the trigger, and the left hand was positioned 16 in. (406 mm) from the muzzle.*

				Amounts Found, μg			Ratio of Amounts, right/left		
Test	Weapon	Action	Hand	Lead	Antimony	Barium	Lead	Antimony	Barium
1	Cooey .22 rifle	bolt	right	25	0.04	0.06	1.2	0.67	1.5
			left	21	0.06	0.04			
2	Cooey .22 rifle	bolt	right	11.4	0.03	0.02	1.14	1	1
			left	10	0.03	0.02			
3	Cooey .22 rifle	bolt	right	11.4	0.04	0.003	1.9	0.8	0.15
			left	6	0.05	0.02			
4	Cooey .22 rifle	bolt, repeater	right	65	0.5	0.1	1.1	1.02	0.09
			left	60	0.49	1.16			
5	Cooey .22 rifle	bolt, repeater	right	90	1.61	3.38	1.2	1.1	1.3
			left	75	1.42	2.69			
6	Cooey .22 rifle	bolt, repeater	right	115	1.97	8.98	0.96	1.1	1.8
			left	120	1.86	4.95			
7	Dreyse .22 rifle	trap door	right	100	4.6	8.8	2.6	2.7	6.3
			left	39	1.7	1.4			
8	Dreyse .22 rifle	trap door	right	25	0.9	0.81	0.67	3	0.84
			left	38	0.3	0.97			
9	Dreyse .22 rifle	trap door	right	10	0.77	0.79	0.71	1	4.6
			left	14	0.74	0.17			
10	Cooey .22 rifle	semiautomatic	right	5.5	0.72	1.18	0.56	7.2	3.2
			left	9.9	0.1	0.37			
11	Cooey .22 rifle	semiautomatic	right	8.7	1.2	0.79	1.6	0.6	0.8
			left	5.5	2.1	0.99			
12	Cooey .22 rifle	semiautomatic	right	7.5	0.08	1.24	1	0.03	2.9
			left	7.5	2.64	0.43			

TABLE 3—*Trace elements found as a function of barrel length in longarms. The right hand pulled the trigger and the left hand was on the barrel.*

		Barrel Length			Amounts Found, μg		
Test	Weapon	in.	mm	Hand	Lead	Antimony	Barium
1	Cooey .22 rifle, semiautomatic	30	762	right	5.5	0.24	0.89
				left	5.5	0.11	0.39
2	Cooey .22 rifle, semiautomatic	30	762	right	9.4	0.12	0.48
				left	7.0	0.05	0.89
3	Cooey .22 rifle, semiautomatic	30	762	right	8.5	0.2	0.46
				left	4.4	0.27	0.94
4	South American rifle, .22, semiautomatic,	5	127	right	50	0.87	0.31
	sawed off			left	50	0.67	1.67
5	South American rifle, .22, semiautomatic,	5	127	right	23	0.11	1.26
	sawed off			left	21	0.21	4.43
6	South American rifle, .22, semiautomatic,	5	127	right	23	0.21	2.5
	sawed off			left	25	0.70	4.1
7	Explorer AR-7 rifle, .22, semiautomatic,	5	127	right	150	9.34	0.74
	sawed off			left	140	4.9	0.75
8	Explorer AR-7 rifle, .22, semiautomatic,	5	127	right	75	6.7	4.2
	sawed off			left	100	10.3	3.6

TABLE 4—*Comparison of results from some actual cases with data from laboratory tests involving one shot fired from regular target-shooting position.*

Test	Type of Case	Weapon	Ammunition	Time Lapse, h	Hand	Amount of Trace Element Found, µg		
						Lead	Antimony	Barium
1	murder	.22 rifle, single shot, bolt action	CIL	2	right	52	0.12	5.98
					left	80	0.72	3.96
	test	.22 rifle, single shot, bolt action	CIL	0	right	15	0.04	0.2
					left	12	0.08	0.2
2	murder	.22 rifle, semiautomatic, sawed off	CIL	24	right	50	0.6	4.4
					left	36	1.51	7.38
	test	.22 rifle, semiautomatic, sawed off	CIL	0	right	44	0.87	0.31
					left	44	0.67	1.67
3	suicide	20-gage shotgun	CIL	10	right	63	0.63	1.35
					left	83	2.57	4.59
	test	20-gage shotgun	CIL	0	right	20	0.38	0.96
					left	37	0.1	0.62
4	homicide	.22 rifle, single shot, bolt action	CIL	16 (in custody)	right	210	1.63	6.64
					left	50	0.35	0.51
	test	.22 rifle, single shot, bolt action	CIL	0	right	30	0.1	1.06
					left	21	0.1	0.96
5	suicide	12-gage shotgun	CIL	6	right	87	0.15	3.62
					left	215	0.13	2.48
	test	12-gage shotgun	CIL	0	right	30	0.26	0.89
					left	30	0.20	0.93
6	suicide	.303 rifle	CIL	3	right	58	0.07	1.66
					left	63	0.04	2.47
	test	.303 rifle	CIL	0	right	23	0.04	0.95
					left	15	0.04	0.96
7	suicide	.410 Magnum® pistol	CIL	2	right	52	0.22	2.5
					left	43	0.15	1.6
	test	.410 Magnum pistol	CIL	0	right	62	0.19	1.12
					left	51	0.06	1.15
8	homicide	.38 revolver	CIL	5	right	145	0.59	3.3
					left	160	0.75	4.7
	test	.38 revolver	CIL	0	right	19	0.37	4.7
					left	5	0.06	0.7

9	murder	.22 rifle	CIL	3	right	439	0.15	11.59
					left	245	0.10	7.74
	test	.22 rifle	CIL	0	right	34	0.12	9.72
					left	11	0.08	2.78
10	homicide	9-mm pistol	CIL	3	right	59	0.48	3.7
					left	42	0.79	2.8
	test	9-mm pistol	CIL	0	right	25	0.33	1.74
					left	25	0.45	0.9

TABLE 5—*Trace elements found after time lapse between firing and sample collection. The weapon used was a .38-caliber revolver and the ammunition was CIL. The right hand was the firing hand.*

Test	Incident	Time lapse, h	Hand	Amounts Found, μg		
				Lead	Antimony	Barium
1	1 shot fired, no loading or unloading	0	right	71	0.45	0.35
			left	20.3	0.16	0.15
2	1 shot, loaded, fired, unloaded cartridge cases; weapon: Colt	3	right	330	ND[a]	8.43
			left	293	ND	9.23
3	1 shot, loaded, fired, unloaded cartridge cases; weapon: Colt	6	right	108	ND	0.91
			left	45	ND	0.73
4	2 shots, loaded, fired, unloaded and handled cartridge cases; weapon: Colt	7	right	43	ND	0.59
			left	57	ND	0.71
5	4 shots, loaded, fired, unloaded and handled cartridge cases; weapon: Charter Arms	0	right	763	5.7	74
			left	245	2.2	11.7
6	4 shots, loaded, fired, unloaded and handled cartridge cases; weapon: Charter Arms	0	right	393	3.56	39.7
			left	183	1.73	6.0
7	4 shots, loaded, fired, unloaded and handled cartridge cases; weapon: Charter Arms	3	right	>1256	13.8	34
			left	1197	5.9	26.9

[a]ND = Not determined because of experimental difficulties.

residue on the firing hand than the nonfiring hand [9]. The ratio of the amount of residue on the firing hand to that on the nonfiring hand is generally significantly greater than 1 [9].

For longarms, the ratio of amounts of trace elements on the firing to nonfiring hand depends on the action of the longarm. Table 6 shows that a .22 rifle with a bolt action

TABLE 6—*Ratios of trace element deposit on hands after firing a longarm. The weapon used was a Cooey single-shot rifle, .22 caliber, bolt action. The right hand pulled the trigger and the left hand was 16 in. (406 mm) away from the muzzle.*

		Amounts Found, μg			Ratio of Amounts, right/left		
Test	Hand	Lead	Antimony	Barium	Lead	Antimony	Barium
1	right	15.2	0.23	1.19	0.84	0.72	0.52
	left	18.2	0.32	2.27			
2	right	27.6	0.28	5.3	1.2	1.3	1.3
	left	22.6	0.21	4.2			
3	right	45.4	0.79	5.1	1.2	1.1	2.0
	left	37.8	0.73	2.5			
4	right	14.2	0.56	1.78	0.49	1.0	2.0
	left	29	0.55	0.89			
5	right	21.5	0.72	1.4	0.98	1.3	0.88
	left	22	0.57	1.6			
6	right	31.4	0.06	0.95	1.7	0.86	0.99
	left	18.7	0.07	0.96			
7	right	128	0.51	0.99	3.9	3.2	1.94
	left	33	0.16	0.51			
8	right	11.9	0.08	0.24	0.37	0.67	0.59
	left	32.2	0.12	0.41			
9	right	10.4	0.18	0.67	1.13	3.6	1.3
	left	9.2	0.05	0.53			
10	right	17.6	0.16	0.59	1.7	1.8	1.2
	left	10.4	0.09	0.50			

generally, with some exceptions, yields a ratio of approximately 1. In the case of the .22 rifle with the trap door action, a significant amount of residue escapes at the chamber which makes, in some instances, the amount of one or more of the elements on the firing hand considerably higher than the nonfiring hand. While considering the ratios, all the elements do not follow the same pattern. For example, in Table 2, Test 3, while the lead ratio is 1.9, the barium ratio is 0.15. In the case of Table 2, Test 12, the antimony is higher on the nonfiring hand while the barium is high on the firing hand. This is not surprising since the origin of barium is the primer while the lead and antimony could arise both from the primer and the bullet. It is not definitely known whether the hand deposit is from the trigger end leakage or from the muzzle or a combination of both. It appears to arise from both ends, as seen by higher deposits on the firing hand from guns with actions that are prone to leak more residue at the breach. At the same time the high deposit on the nonfiring hand with weapons having sawed-off barrels (Table 3) indicates that some of it arises from the muzzle as well.

A study of suicides and homicides, actual as well as simulated cases involving a variety of weapons, shows that the ratio of levels on the firing to the nonfiring hand is unpredictable (Tables 4 and 5). The reason for this is undoubtedly a combination of many factors such as the way the weapon was held during the shooting, handling the weapon and cartridge cases after the shooting, and, with live subjects, the loss and redistribution of trace elements. The firing hand does not always contain the higher amount of all the trace elements. While one element may be higher on the firing hand, another may be lower. The antimony to barium or lead to antimony ratio is therefore of no value in case work. There is no particular reason, however, for all the trace elements to appear in higher or lower amounts. These elements are not all present together in the same particle. Scanning electron microscopy studies [*18*][2] of the residue particles on the firing hand show that lead, antimony, or barium are often present alone in different particles, although frequently lead and antimony occur together.

Residue on the Palm Versus Back of the Hand—It has been suggested that the distribution of gunshot residue on the hands of a person would enable one to say whether the subject fired a gun or merely handled a fired weapon. When a person fires a gun, the residue is expected to be deposited more on the back of the firing hand than the palm [*4*]. Merely handling a fired weapon would leave residue on the palm but not on the back of the hand. To check whether this theory holds true in actual practice, a series of firings was done under clean laboratory conditions where the subjects just fired the weapon. They were not allowed to load or unload the gun or otherwise contaminate the hand. The back and the palms were carefully washed using a stream of 5% nitric acid. The results of the analysis are given in Table 7.

Of five tests in which one shot was fired, in three cases all the elements were higher on the back of the hand than the palm. In all tests, antimony and barium were high on the back. When a recently fired gun was just handled, two of four tests showed higher amounts of all the elements on the palm than on the back, while three of four showed at least two elements higher on the palm. In general, therefore, under laboratory conditions this theory may be valid.

To test this under case conditions several cases were simulated. In this series of tests, the subjects were asked to load the gun and either shoot or simply handle a fired gun. The samples were taken 1 h after shooting. The results are given in Table 8.

The results show that the distribution of trace elements is not as clearly predictable as in controlled laboratory shots. For example, in Tests 1 to 3 of Table 8, where one shot was fired in each case, the amount of lead detected was more on the palm than on the back of the firing hand. In Test 3 the amounts of all three elements are higher on the palm. The distribution reflects the random spread of the residue upon firing. Some of the residue gets deposited on the sides of the fingers and other areas which are intermediate between the back and the palm and are difficult to reproduce. Also, the loss of residue by normal activity subsequent to firing and the redistribution that is possible further complicate the distribution pattern.

The distribution pattern of the residue is unreliable as a means of establishing whether a person has fired a gun or merely handled one. In suicides and some homicides, it is not uncommon to find more residue on the palm than on the back of the firing hand. In some cases the firer may handle the fired cartridge cases subsequent to shooting. This would leave more residue on the palm. This has been observed by other workers [*4,13*].

Conversely, when a person has merely handled a fired weapon some residue might be deposited on the back of the hand because of the handling itself or through deposition on the sides and between the fingers which may be removed with the sample from the back. Also, the residue from the palm may be preferentially removed as a result of normal activities or attempts to wipe the palm against clothing or other objects. The net result of this may be that more residue is present on the back than on the palm although the person had not fired the gun. Therefore, unless the circumstances are exceptional, it is unwise to derive firm conclusions from the distribution data.

[2] Aerospace Corp., Los Angeles, Calif., private communication, 1975.

TABLE 7—*Distribution of trace elements on the firing hand. The weapon used was a .38-caliber revolver and the ammunition was CIL. The right hand was the firing hand.*

		Amount on the Back, μg			Amount on the Palm, μg		
Test	Incident	Lead	Antimony	Barium	Lead	Antimony	Barium
1	1 shot fired	12.6	2.6	3.31	10	0.4	0.7
2	1 shot fired	13.8	0.33	0.3	16.58	0.26	0.26
3	1 shot fired	35.2	4.6	0.9	32.4	0.88	0.22
4	1 shot fired	17.6	0.45	1.1	22.8	0.17	0.88
5	1 shot fired	45.8	1.47	1.22	41.4	1.06	0.47
6	handled fired gun	34.8	0.04	0.14	41	0.26	0.4
7	handled fired gun	60.6	0.16	0.31	44	0.15	0.33
8	handled fired gun	61.8	0.22	1.9	132	0.35	7.13
9	handled fired gun	42.9	0.14	0.54	28.2	0.18	0.64

TABLE 8—*Distribution of trace elements—firing versus handling of a gun. The weapon used was a .38-caliber revolver and the ammunition was CIL. The right hand was the firing hand.*[a]

			Amount of Elements Found, μg		
Test	Incident	Location	Lead	Antimony	Barium
1	1 shot fired	right back	40.4	0.42	0.26
		right palm	54.8	0.34	0.16
		left back	16.8	0.13	0.10
		left palm	13.1	0.18	0.02
2	1 shot fired	right back	11.1	0.10	0.31
		right palm	27.4	0.11	0.22
		left back	7.82	0.07	0.13
		left palm	18.98	0.05	0.08
3	1 shot fired	right back	10.1	0.04	0.05
		right palm	35.2	0.26	2.2
		left back	7.8	0.04	0.25
		left palm	9.5	0.08	0.18
4	handled fired weapon	right back	3.2	0.02	0.05
		right palm	15.8	0.07	0.13
		left back	3.88	0.09	0.05
		left palm	4.8	0.10	0.11
5	handled fired weapon	right back	8.52	0.06	0.08
		right palm	30.2	0.09	0.2
		left back	3.42	0.08	0.13
		left palm	5.2	0.04	0.03

[a]Simulated cases. Samples were collected 1 h after the incident.

Residue from Acts Other than Firing

In actual cases, it is often important to comment on the possible sources, other than firing, which may give rise to gunshot residue. A series of situations were simulated and the trace element deposits on the hands were studied. The results are given in Table 9.

Gunshot residue can be deposited on a hand that is close to a gun at the time of shooting. This situation could arise when a person is struggling with another and the gun is discharged during the struggle. The amount of trace elements on the firer and the other person could be similar, or there may be even more on the nonfirer's hands under some circumstances. For example, if the other person's hand was closer to the muzzle than the firer's, discharge residue from the muzzle which contains considerable amounts of trace elements may be deposited on the hand. The absolute amount of residue, therefore, does not give a clear indication as to who pulled the trigger.

Gunshot residues are not deposited in significant amounts on hands which are farther than about 3 ft (1 m) away, especially outside of the bullet path. This conclusion has also been reached by Cornelius et al [*4*].

Residues are also deposited on the hands of a person who picks up and handles a gun which has been fired. The handling has to be deliberately done, particularly at the muzzle, in order to pick up significant amounts of deposit. The amount of residue also depends on how recently the gun was fired (Table 9). Handling a gun which was fired just minutes before deposits significant amounts of residue. The amount is less if the handling is done 2 h after firing. Handling a gun which was fired 2 days earlier does not leave any residue. It is not obvious as to why the amount of deposit left on the gun decreases with time. Scanning electron microscopy experiments [*18*] show that gunshot particles are

TABLE 9—*Deposition of trace elements on hands at a shooting scene. The right hand was the firing hand.*

Test	Incident	Weapon	Hand	Amount Found, μg		
				Lead	Antimony	Barium
1	hands 2 in. (51 mm) from the gun being fired, right hand near muzzle, left hand near trigger	.22 rifle, blowback action, sawed off	right	34	1.1	6.4
			left	15	2.3	5.2
2	hands 2 in. (51 mm) from the gun being fired, right hand near muzzle, left hand near trigger	.22 rifle, blowback action, sawed off	right	32	3.5	3.7
			left	32	6.9	8.6
3	handled the gun fired less than 1 min earlier	.22 rifle, blowback action, sawed off	right	34	3.15	3.1
			left	32	2.4	0.9
4	handled the gun fired less than 1 min earlier	.32 revolver	right	19	0.64	0.38
			left	16	0.09	0.30
5	handled the gun fired 2 h earlier	.32 revolver	right	32	0.29	0.26
			left	22	0.21	0.29
6	1 shot fired	.303 rifle	right	30	0.62	1.18
			left	50	0.41	0.35
7	handled the gun fired 2 days earlier	.303 rifle	right	13	0.06	0.5
			left	11	0.06	0.3
8	handled the target containing the bullet hole, contact shot	.22 rifle	right	60	4.53	6.69
			left	68	6.06	7.85

generally very small in size. These may remain loosely on the surface of the gun and be completely lost to the environment after several hours.

Handling the target containing the bullet hole may leave significant amounts of residue on the hands, particularly if the muzzle-target distance is short and a large amount of residue from the muzzle is deposited around the bullet hole. Thus it is possible to find residues on the hands of the victim of a shooting incident who had clutched the wounded area.

Persistence of Residue

The persistence of gunshot residue on the hands has been studied [*9,17*] and is an important consideration in cases where the suspect is apprehended some time after the incident. It is not easy to generalize regarding the time factor. The removal of residue depends on the activities during the time interval. With normal activities the time up to which residues were detected has been reported as from 30 min to 17 h [*9,17*].

Generally, samples are not taken from the suspect for several hours at least. If the residue does not remain more than approximately 2 h as reported [*17*], then the entire technique is useless for practical case applications. Analysis in this laboratory of nearly 100 cases wherein it was reasonably certain, for example by admission by the subject, that the subject did fire a gun showed that, with live subjects, significant residue deposits were detected up to 24 h. Residues were generally undetectable after 24 h.

In addition to firing, subsequent acts of handling the weapon or the spent cartridge cases increase the hand deposit. Therefore, in actual cases the initial deposit is considerably larger than in laboratory tests and it takes much longer for the larger amount of residue to dissipate. This is illustrated in Table 5. Test 1 shows the amount of deposit on the hand under laboratory conditions. The amounts of trace elements are much higher in Test 7 which included firing multiple shots as well as loading, unloading, and handling fired cartridge cases. With Test 7 it is seen that the residues are present even after 3 h of normal activities. Even after such a length of time the amount of residue left is higher than that deposited by one shot fired under laboratory conditions. This is an important finding and explains why residues are detectable in actual cases where the sample is usually taken a few hours after the incident.

Conclusions

1. High amounts of lead, antimony, and barium compared to handblank levels on the hands of a subject indicate the presence of gunshot residue.

2. The amount of trace elements found in laboratory test shots are usually lower than those in actual cases.

3. The ratio of residue on the firing hand to the nonfiring hand can vary unpredictably in actual case situations because of loss or transfer of residue from one hand to the other during normal activities prior to sampling.

4. The concept that there are higher amounts of residue on the back of the hand of the firer while higher amounts exist on the palm of a person who merely handled a gun is not always valid or reliable in case work.

5. Residues persist on the hands for a longer time in actual cases (up to 24 h in many instances) than indicated in laboratory experiments (approximately 2 h).

6. The antimony to barium or lead to antimony ratio [*17*] is of no real significance in case work.

7. The technique is effective in detecting gunshot residue on hands. However, it is not always possible to determine how it got there. In exceptional cases where clearly one hand has more than the other and similar data are obtained by simulating the alleged in-

cident in the laboratory using the same gun and ammunition, opinions on the origin of the residue can be given.

8. Longarms generally do not deposit as much gunshot residue on the hands as do handguns. Both kinds of weapons should be tested individually since guns of same type may deposit different amounts of residue.

9. Even if a gun does not produce residue at the breach, the firer can receive residues on the hands by several other means such as handling the fired weapon, the muzzle, spent cartridge case, or the target containing the bullet hole.

10. In our work, positive evidence of gunshot residues were found in approximately 90% of the cases (52 of 58 suicide victims and 48 of 55 live subjects of homicide and other offenses; the negatives include those done to eliminate some suspects as well). These findings contrast with 20 to 30% positive findings reported by a number of other laboratories.[3] The reasons for this may be many and some of the following factors are among them.

The law enforcement officers connected with our laboratory are well trained in the use of our kits and receive instructions to consider carefully the circumstances in each case. For example, with live subjects handwash samples will not generally be taken 24 h after the incident. Second, the entire hand is washed so that even the smallest particles left on any part of the hand are collected and there is enough time for these to dissolve while in storage or transport. (It is known that gunshot residues, particularly from the bullet, require time to dissolve.)

All evaporations are done by freeze drying. The solution is not heated in any part of the processing. Radioactive tracer studies show that trace amounts of antimony are totally adsorbed on glass upon heating. If antimony is lost in this way, for those laboratories which rely only on antimony and barium data, an otherwise positive result would become inconclusive.

11. Contamination by blood which may be present on the hands of the suspect does not present any problem. Since typical values in case work for lead is aroung 100 μg, for antimony approximately 0.5 μg, and for barium approximately 1 μg, the contributions from blood are negligible.

Acknowledgments

The author wishes to acknowledge the help of the members of the staff of the Centre over the number of years this project continued; to all those who helped in test firings; to the members of the Firearms Section for excellent co-operation; and especially to Mr. D. M. Lucas, Director; Mr. E. G. Clair, Head, Chemistry Section; and Mr. R. C. Nichol, Head, Firearms Section, for help and criticism during all phases of the work.

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