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Analysis of Gunshot Residues on Human Tissues and Clothing by X-Ray Microfluorescence

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ABSTRACT: The analysis of gunshot residues on human tissues and clothing in suicide, homicide, suspicious death, or attempted murder events, permits the forensic scientist to confirm the possibility of an entry wound caused by a gunshot bullet from a pistol, revolver, rifle, etc. The residues to be detected are lead (Pb), antimony (Sb), barium (Ba) usually from the primer, copper (Cu) and zinc (Zn) usually from the metal jacket bullet and iron (Fe) possibly from the barrel of the gun used. The presence or absence of these elements and their relative concentrations can help in the interpretation of the event.

KEYWORDS: forensic science, criminalistics, gunshot residue, X-ray microfluorescence, shooting distance

In homicide or suicide events, the pathologist, during the autopsy, excises tissues from wounds of the victim's body (1). The sample excised may include both skin and other body tissues. Small body parts, such as a finger, a tongue, a skull fragment, etc. . . , may also be examined. A tissue sample from other parts of the victim's body that is away from any wound areas is also taken as an analytical control.

In murder or attempted murder events, if the bullet passes through clothing (blouse, T-shirt, jacket, coat, etc.), the outline of the entry of the fabric can be directly analyzed by X-ray microfluorescence. Qualitative scans and elemental maps around the entry of a bullet on tissues and fabric will reveal the elements of interest and their relative distribution and intensities.

X-ray spectra and elemental maps (2) clearly show the elements present, their relative concentrations, and distributions around the wound entry. This article presents the instrumentation used and discusses results of our efforts to develop systematic ways using qualitative X-ray microfluorescence analyses to interpret different types of gunshot residues around bullet entry wounds.

Instrumentation

The gunshot analysis results were obtained using a Kevex Omicron (3) energy dispersive X-ray microfluorescence spectrometer equipped with a Rhodium anode microfocus X-ray tube. All the analytical results presented here were obtained using maximum operating tube voltage (50 kV) and different amperage (mA) levels to optimize data throughput. The results presented in this paper were achieved using a 300 micron final beam collimator. However, several different collimators (50, 100, 500 microns or larger) may be interchanged to obtain the appropriate spatial resolution for the application of interest. Excellent elemental sensitivity can be achieved due to the close coupling of sample with the X-ray source and detector. For metallic elements typically found in gunshot residues sensitivities are in the low part per million range.

The X-ray microfluorescence is a relatively new forensic analytical technique being used at the "Laboratoire de Sciences Judiciaires et de Médecine Légale" of the Public Security Minister of the Quebec Government. One of the key advantages of the Kevex Omicron (Fig. 1) is that it may be used for many different forensic applications such as explosives, ballistics, forensic chemistry and toxicology, especially when evidence's samples is small or limited. Sample analysis is rapid, nondestructive, and nonconsumptive. No or minimal sample preparation is required other than finding a suitable polymer thin film or fixture on which to mount the sample. The analysis of flesh tissues and other wet samples can be accomplished without carbon or other conductive coatings and vacuum. A search for a 1–5 microns gunshot residue (GSR) particle is not possible by X-ray microfluorescence because the smallest beam collimator diameter is 50 μm. The SEM/EDX meets those spatial resolution requirements. Conventional GSR analysis by SEM/EDX is capable of identifying particles as small as 0.5 μm in diameter (4). However, elemental sensitivity of the Kevex Omicron is approximately 100× better than SEM/EDX (Scanning Electron Microscopy/Energy Dispersive X-ray).

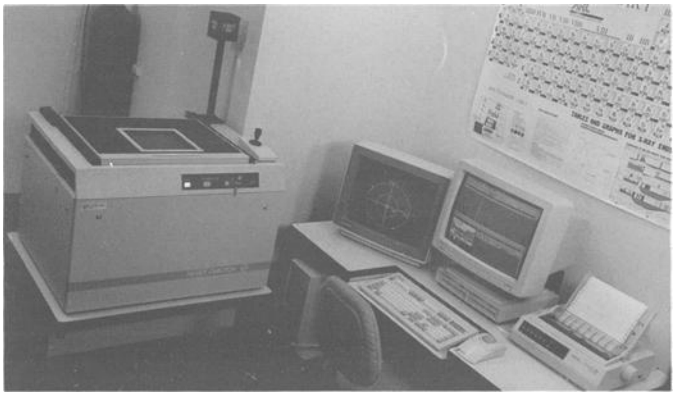

FIG. 1—*Kevex Omicron.*

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Experimental

The sample to be analyzed is placed in the sample holder, usually a 31-mm sample cup or 35-mm slide mount with a thin polymer film stretched across the opening. Different polymer films of varying thicknesses can be used as sample supports. In this paper, micron thick polypropylene film was used. Analytical conditions used were 50 kV, mA adjusted to achieve a deadtime of 45% with a 300 micron final collimator at atmospheric pressure.

The sample is putted on a stage and positioned for analysis with a computer joystick. All samples are scanned in the area of interest (typically 2 by 2 cm for human tissues) with the stage under computer control to determine the presence and relative abundance of Pb, Ba, Sb, Cu, and Fe. Scanning time is less than 60 min. Figure 2 shows elemental maps of interest.

Before analysis all human tissue samples are kept frozen. Analysis is done with the sample still frozen. The only preparation is to cut the sample to fit into the sample holder. After the analysis, samples are preserved in a freezer for further analysis if necessary. Different types of human tissues can be analyzed (Fig. 3).

Results and Discussion

Many types of gunshot residues can be found around an entry wound (see Tables 1 to 4), the most frequent are summarized below:

A. Pb, Sb, Ba, Cu, Zn, Fe
B. Pb, Sb, Ba, Fe
C. Pb, Sb, Cu, Fe
D. Pb, Cu, Fe
E. Pb, Sb, Fe
F. Pb, Fe

Generally as the shooting distance increases, the spectral intensity and number of elements found decreases, as shown in this summary from A to F.

Pb comes from the bullet, the primer, and also from some small previous deposit in the barrel. Sb comes from the bullet and/or from the primer. Ba comes from the primer only (5,6). Cu and Zn usually come from the metal jacket of the bullet and Fe usually comes from the barrel of the gun. When possible, the bullet extracted from the fatal gunshot wound or an identical one can be analyzed to determine if Sb has been added to Pb in the bullet itself. The metal jacket or casing of the bullet should be analyzed as well, to explain the presence of Cu, Zn, and Fe which can come from an European type of metal jacket bullet.

When entry wounds are made from a firearm discharge at contact or point blank range, residue results of type A or B may be found. When entry wounds are made from a firearm discharge at greater distances, results from type C through F are typically found. When it is possible, depending of the event, the approximate shooting distance is made initially by measuring the diameter of the gunshot scatter or the powder stippling on the victim's body or clothing. Important variables to consider when interpreting shooting distances are the type and caliber of the actual gun used and also the type of cartridge and bullet. The ballistic specialist will try, with representative tests firings, to obtain a similar pattern of diameter by shooting on a large sheet of paper with the gun used or a similar one at increasing distances. He will then be able to determine some of the conditions under which the victim was shot (7).

Examples

The analysis of an entry wound caused by a .38 special revolver at point blank range in a suicide case can give results of type A or B. But, using a .22 LR caliber rifle, results of type C or D can be obtained at point blank range. The absence of Sb in the bullet and its presence in the entry wound indicates that it comes from the primer. Figure 4 shows a typical result data sheet.

After collection of XRMF results, all the principal elements of the investigation must be considered in the interpretation of the X-ray gunshot residue results. These principal elements are: Type

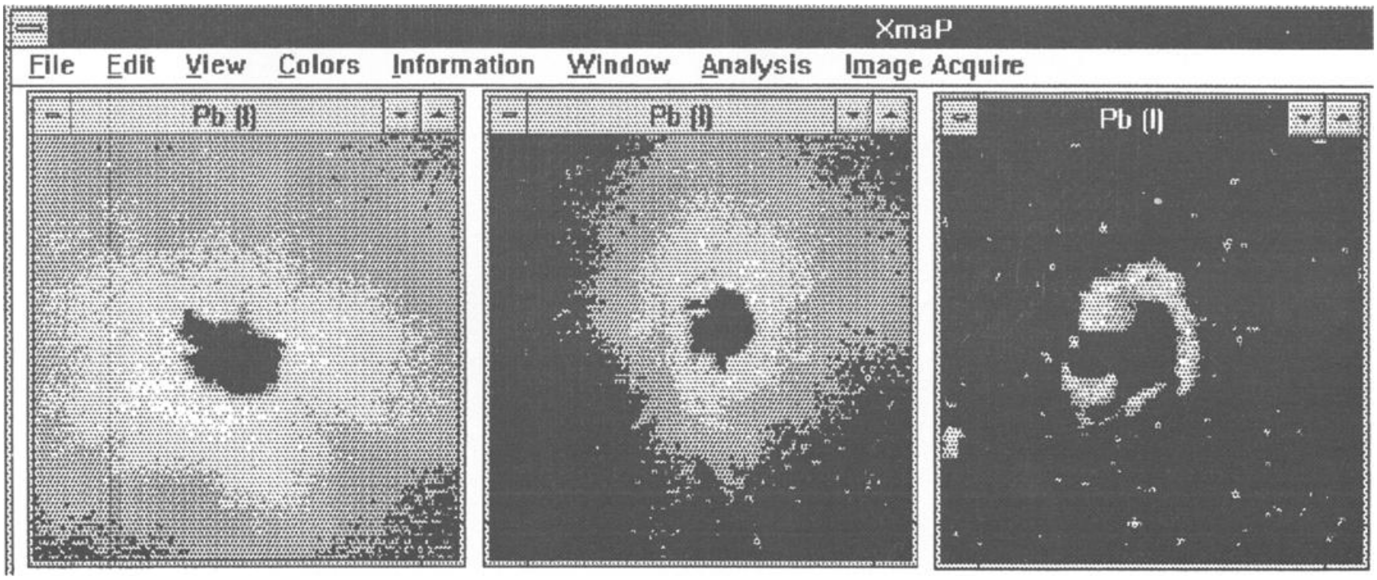

FIG. 2—*Scans of three firearm discharges on a piece of paper (117 cm in diameter) at different distances; 2 cm for the left map, 5 cm for the center map, and 30 cm for the right map. We can see that the relative abundance of lead is decreasing with the shooting distance. The firearm used was a .38 special Smith and Wesson revolver with .38 special 158 g metal point Western X Winchester cartridge. The right map was enlarged twice to get a more detailed distribution of lead. The area scanned for each map was 6 by 6 cm with a 300 micron final beam collimator.*

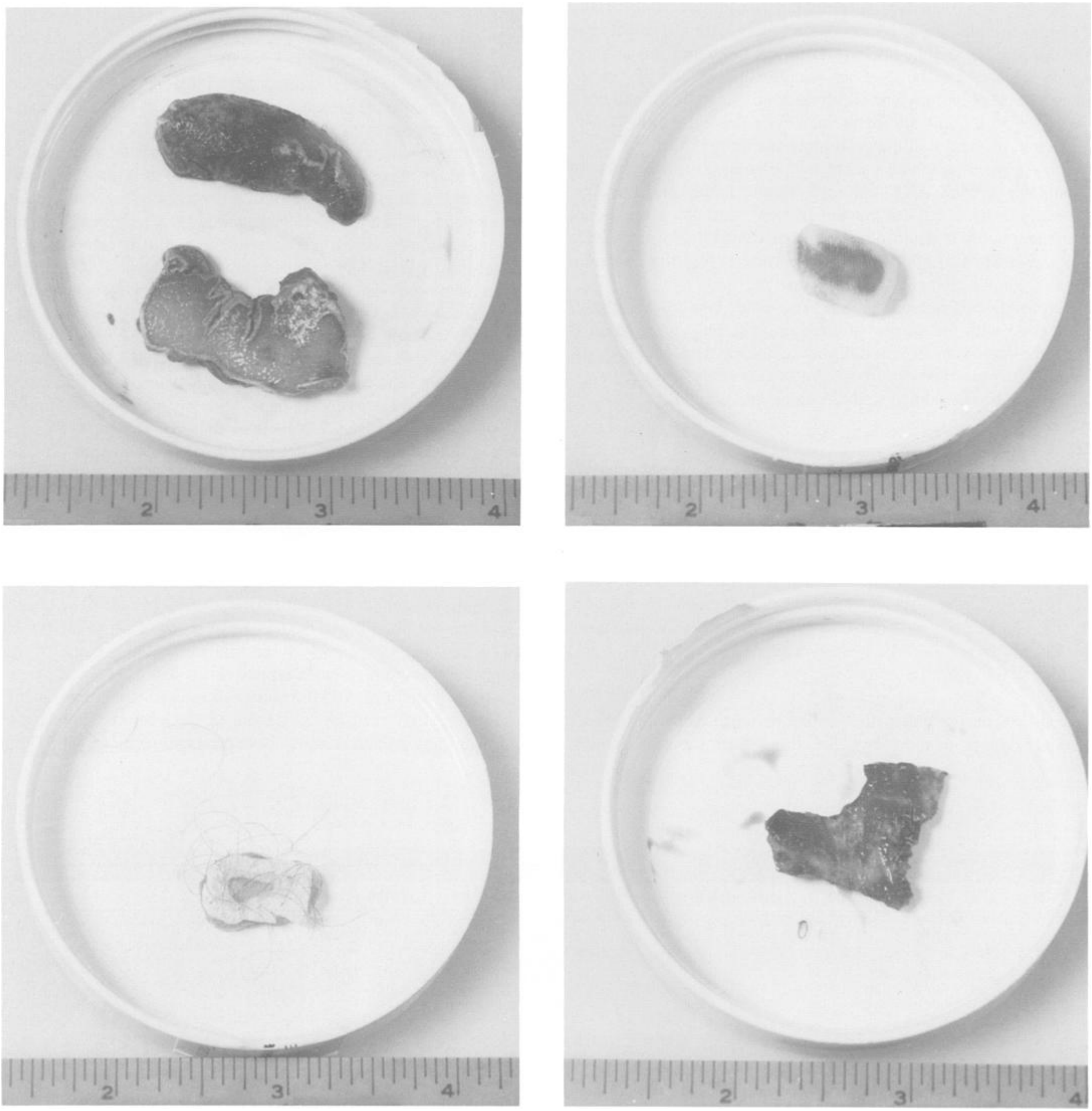

FIG. 3—*1. A skull fragment (top left). 2. A part of a finger (top right). 3. A control sample from the leg (bottom left). 4. A thorax entry wound (bottom right).*

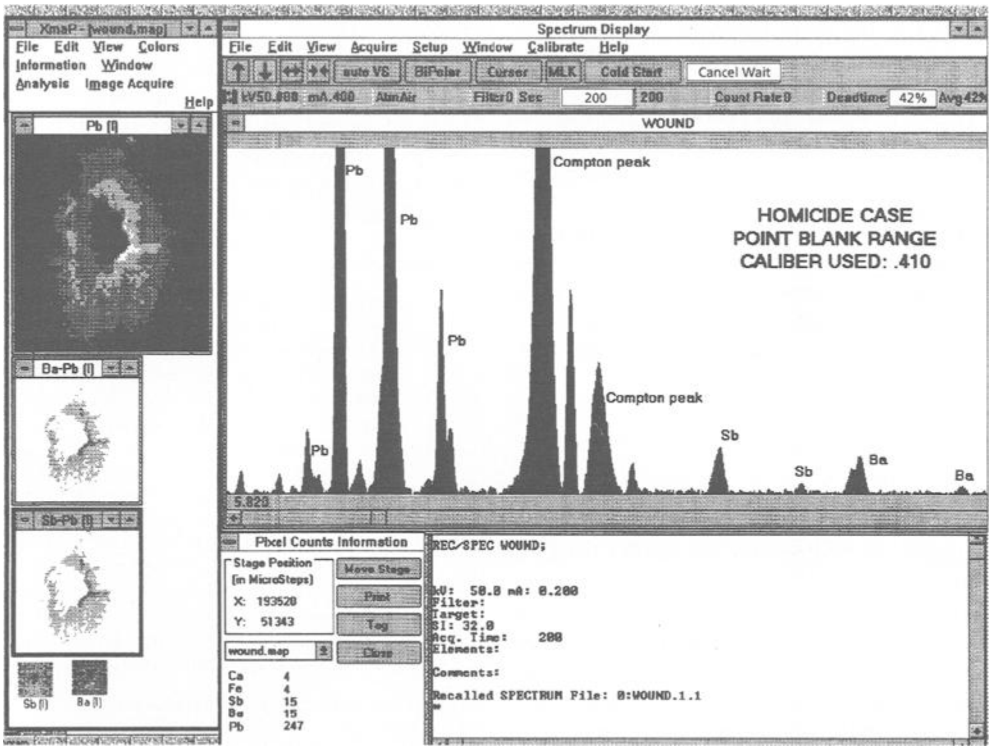

FIG. 4—*Results obtained from an entry wound in the neck region at point blank range in a homicide case. The caliber used was a .410 gage shotgun. The area scanned was approximately 5 by 5 cm. The analysis reveals presence of lead (Pb), antimony (Sb), and barium (Ba).*

TABLE 1—*Details of gunshot entry wound analysis in 33 suicide cases in 1994.*

Number of Events	Type of Weapon	Caliber/Gage	Results Found
10	Shotgun	12 gage	Pb,Sb,Ba,Fe (8)
			Pb,Sb,Fe
			Pb,Fe
4	Shotgun	20 gage	Pb,Sb,Ba,Fe (3)
			Pb,Fe
4	Shotgun	.410 gage	Pb,Sb,Ba,Fe, (3)
			Pb,Fe
4	Rifle	.22	Pb,Sb,Ba,Fe (2)
			Pb,Sb,Fe,Cu
			Pb,Fe
2	Rifle	30.06	Pb,Sb,Ba,Fe,Cu,Zn
			Pb,Fe,Cu
1	Rifle	.306	Pb,Sb,Ba,Fe,Cu,Zn
1	Rifle	.32	Pb,Sb,Ba,Fe,Cu,Zn
3	Revolver	.357	Pb,Sb,Ba,Fe,Cu,Zn
			Pb,Sb,Ba,Fe
			Pb,Fe,Cu
1	Revolver	.38	Pb,Sb,Ba,Fe
1	Revolver	.45	Pb,Sb,Ba,Fe
1	Pistol	9 mm	Pb,Sb,Ba,Fe
1	Pistol	.765	Pb,Ba,Fe,Cu,Ni

of event to be determined; suspected suicide, murder, etc., the origin of the human and cloth samples, physical evidence by investigation of the wound(s), type (handgun, shotgun, etc.) and caliber (.22, .38, .45, etc.) of gun used, type of bullet used (metallic composition), scenario of the event, and possible interposed targets and their effects. The elements found on an entry wound are dependent or previously dependent of the ammunition used. It is an application of the Locard's Principle: When there is contact between two objects, independent of their nature, there is always, at least, a transfer of one on the other, in big or small amount that can be easily detectable or not.

TABLE 2—*Details of gunshot entry wound analysis in eight homicide cases in 1994.*

Number of Events	Type of Weapon	Caliber/Gage	Results Found
3	Shotgun	12 Gage	Pb,Sb,Ba,Fe
			Pb,Sb,Fe
2	Rifle	.303	Pb,Sb,Ba,Fe,Cu,Zn
			Pb,Fe,Cu,Zn
2	Revolver	.357	Pb,Sb,Ba,Fe,Cu,Zn
			Pb
1	Pistol	9 mm	Pb,Sb,Ba,Fe

TABLE 3—*Details of gunshot analysis on clothing in five cases of attempted murder in 1994.*

Number of Events	Type of Weapon	Caliber/Gage	Results Found
2	Shotgun	12 Gauge	Pb,Sb,Ba,Fe
			Pb
1	Rifle	.308	Pb,Sb,Fe,Cu
2	Pistol	9 mm	Pb,Fe,Cu,Zn

TABLE 4—*Details of gunshot analysis in four fatal accidents in 1994.*

Number of Events	Type of Weapon	Caliber/Gage	Results Found
1	Shotgun	12 Gage	Pb,Sb,Fe,Cu
1	Rifle	.22	Pb,Sb,Ba,Fe,Cu
1	Rifle	.308	Pb,Sb,Ba,Fe,Cu,Zn
1	Rifle	30.06	Pb,Sb,Ba,Fe,Cu,Zn

In each case, a blank human tissue and the bullet (or an identical one) are also analyzed to confirm the presence of all elements found in the entry wound.

In a suicide case, (Table 1) with a .765 pistol, Pb, Ba, Fe, Cu, and Ni (nickel) were found. The presence of Ni was intriguing. After analysis of a similar bullet, we found that the metal jacket was made of a copper-nickel alloy.

Also, in some cases, small amount of copper can be found in the entry wound, but not in the ammunition used. The presence of Cu may be explained by a previous use of the weapon with a copper base metal jacket. Some small deposit of the metal jacket was still in the barrel of the weapon. This is the most probable explanation for the presence of copper.

Conclusion

Analysis of human tissues by detecting Pb, Sb, and Ba confirms the type of entry wound caused by a gunshot (firearm discharge) (4). The presence or absence of these and other elements (copper, zinc, iron, etc.) can help to determine the approximate shooting distance. The information can help in the determination of a suspicious deaths (suicide or homicide). Interpretation of gunshot wound demands to consider all available information (8).

Comparison of gunshot scatter and powder stippling from various type of guns at different shooting distances gives information that will enable to better understanding of shooting distances as they relate to gunshot entry wounds (1).

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