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The Form of Gunshot Residue is Modified by Target Impact

REFERENCE: Burnett, B., **"The Form of Gunshot Residue is Modified by Target Impact,"** *Journal of Forensic Sciences,* JFSCA, Vol. 34, No. 4, July 1989, pp. 808-822.

ABSTRACT: In the examination by scanning electron microscopy of hair and polyester fabric that had been shot with a 9-mm pistol at muzzle-to-target distances from 10 to 70 cm, it was discovered that part of the gunshot residue (GSR) deposited on the target is molten at impact. Impact of these molten GSR particles results in flattening, splattering, or some modification of the otherwise spherical form. In the case of hair, microtopography and the probable rapid movement of the hair in the muzzle blast influence the form of GSR. A sample of hair shot within 30 cm often results in GSR finding its way under hair scales. The detection of these form-modified GSR particles on fabric or on (and under) scales of hair indicates a close-proximity shot.

KEYWORDS: forensic science, gunshot residues, microscopy, molten, scanning electron microscopy (SEM), energy dispersive X-ray analysis, fabric, hair, gunpowder

The factors that generate irregular and flattened gunshot residue (GSR) have never been investigated. Irregular and flattened GSR from the hands of shooters was described in the pioneering work of Wolten and his coworkers [*1-3*]. These authors suggest that in the formation of the GSR particles, "spheroidal particles are thought to result by rapid condensation from a vapor, whereas the irregular particles may be produced by the solidification of droplets of molten material on interior surfaces of the gun" [*2*]. There is no speculation whether or not molten particles occur beyond the muzzle or breach of a gun. These authors did not examine muzzle-blast GSR.

Other authors have accepted the assumption presented by Wolten and coworkers that irregular GSR particles are formed in the bore of the gun. Ueyama et al. [*4*] examined muzzle-blast derived GSR for shape, size, and elemental composition. An interesting observation of this study is that for .38 Special ammunition, irregular particles "appear to occur only rarely at target distances of 12 inches and beyond" [*4*]. They speculate that the irregular when compared to the spherical particles "will be subject to more 'drag' and therefore will lose their energy sooner and travel shorter distances" [*4*].

Most work in GSR analysis deals with the examination of tape lifts of hands of a shooter [*1-3,5,6*]. A transfer method obscures the relationship of GSR particles with the target. In this study, it is shown that some GSR is molten when it impacts a close target of fabric and human hair and that this molten GSR will change shape upon striking the target. Partially burnt gunpowder flakes also interact with the target surfaces in ways not previously described.

Received for publication 19 Aug. 1988; revised manuscript received 17 Oct. 1988; accepted for publication 18 Oct. 1988.

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Materials and Methods

Two target materials are considered in this study. The first is fabric of 100% polyester monofilaments (Poly-Jean®) which was obtained from Ted Pella, Inc., P. O. Box 2318, Redding, CA 96099. The smooth monofilaments are approximately 16 μm in diameter. Pieces of this cloth (22 by 22 cm) were mounted on a wood target and shot with a 9-mm Smith & Wesson Model 39-2 pistol. Muzzle-to-target distances were from 10 to 90 cm. The ammunition was 124-gr Remington round-nose (RN) jacketed cartridges. For each sample, a 0.5- to 1-cm square piece of fabric from the border of the bullet hole was removed by cutting with a razor blade. The fabric piece was mounted on a standard scanning electron microscopy (SEM) stub with a liberal coat of carbon paint.

In the second series of experiments human hair (>9 cm long) was mounted on a plywood target (Fig. 1*a*). These targets were shot with either 9-mm Winchester 115-gr RN jacketed cartridges (head stamp WCC 1987) or Winchester 115-gr hollow-point Silvertip cartridges. Muzzle-to-target distances were from 10 to 70 cm. Hair within 1 cm of the bullet hole was removed from the target and mounted on a SEM stub with carbon paint (Fig. 1*b*).

All SEM stub samples were carbon coated and viewed in an ETEC Autoscan scanning electron microscope with simultaneous secondary and backscatter imaging. Elemental composition of the particles was determined by a Kevex 5100 energy dispersive X-ray analyzer.

Observations

GSR on Fabric

Most of the gunshot residue particles on the monofilaments of the fabric appear spherical. There are, however, particles that show either flattening (Fig. 2) or splattering (Fig. 3) or both (Fig. 4). This is especially true for target distances from 20 to 30 cm. Other large GSR particles show a piling up of GSR material around the periphery of the particle (Fig. 5*a* and *b*) as well as some splattering (arrow, Fig. 5*a*). Some of the splatter may take the form of fibers (Fig. 3). Often the spherical GSR particles in close proximity to flattened GSR particles have elemental compositions and ratios essentially identical to that of the flattened GSR particle.

Apparent crystal formation on and within some of the flattened GSR may be observed. For the GSR particle shown in Fig. 6, and for several other particles with this structure, X-ray analysis of the crystals (Fig. 6) shows that they are rich in potassium and are possibly

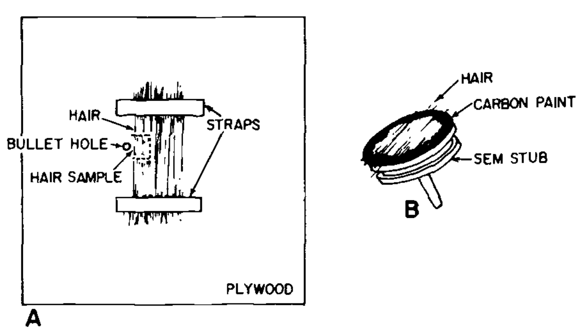

FIG. 1—(A) *Drawing of hair mounted on plywood target;* (B) *mounting the hair on an SEM stub. Sample was taken within 1 cm of bullet hole.*

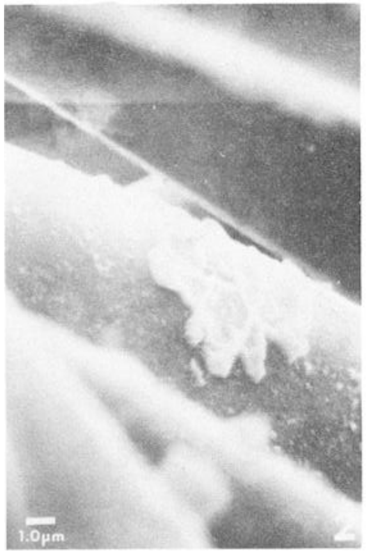

FIG. 2—*Flattened GSR particle on polyester monofilament. Muzzle-to-target distance: 20 cm. Composition: lead.*

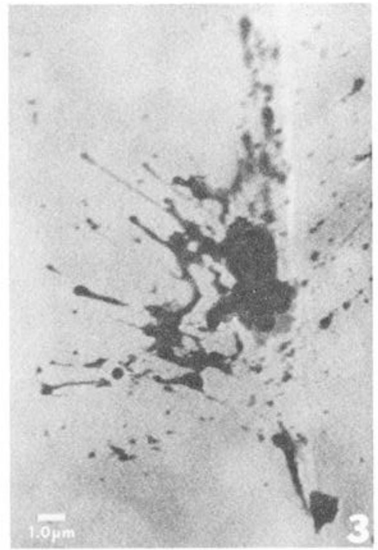

FIG. 3—*Backscatter image of splattered GSR particle on polyester monofilament. Muzzle-to-target distance: 20 cm. Composition: lead-barium (minor: antimony-copper).*

FIG. 4—*Splattered/flattened GSR particle on polyester monofilament. Muzzle-to-target distance: 30 cm. Composition: lead-antimony.*

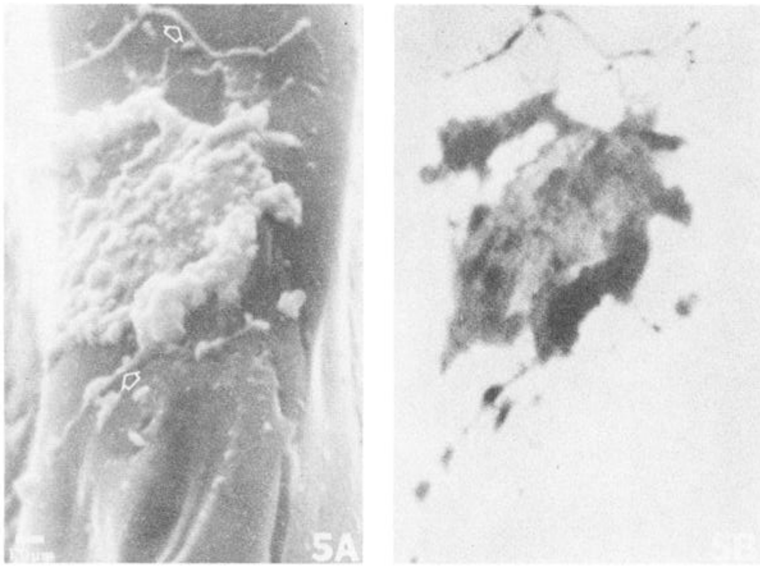

FIG. 5—*Splattered/flattened GSR particle on polyester monofilament. (A) Secondary image showing build-up of material around edges of flattened GSR particle. (B) Backscatter image. Muzzle-to-target distance: 30 cm. Composition: lead.*

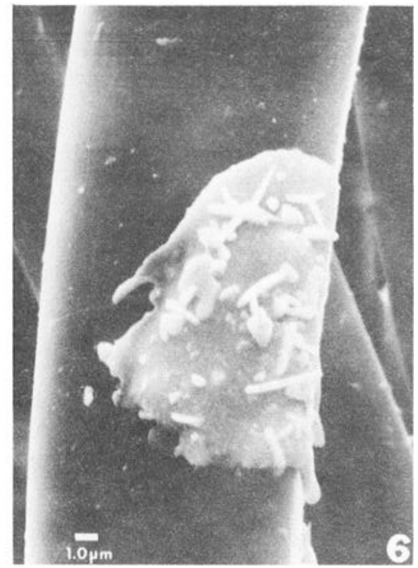

FIG. 6—*Flattened GSR particle with crystals on polyester monofilament. Muzzle-to-target distance: 35 cm. Composition: barium, crystals: potassium or barium-potassium.*

alloyed with barium. Analysis of an area of the GSR particle lacking these crystals shows only barium.

Deformation of the polyester monofilaments may often occur on or near the monofilament contact area with the GSR. In some particles, a slight depression of the monofilament fiber may be seen underlying the flattened GSR particle (Fig. 7). More exaggerated monofilament defects may also be apparent in association with GSR (Fig. 8).

Monofilaments shot at a muzzle to target distance at or greater than 50 cm are impacted by large (>2.0-μm diameter) GSR particles. Some of these particles appear to shatter on contact with a monofilament (Fig. 9); others show GSR particles partially penetrating and adhering to the monofilament surface (Fig. 10).

GSR on Hair

For the hair samples that were shot at 10 cm, most of the GSR particles that coat the hair shafts are less than 0.25 μm in diameter (Fig. 11). A plot (Fig. 12) of GSR abundance for all target distances for the Winchester RN shots shows a dramatic reduction of adhering particles with distance from the muzzle of the gun. A similar plot (not shown) can be produced for the Winchester HPST shots.

The hair samples shot at 20 cm show the large GSR particles as mostly irregular (see Fig. 13). Small spherical particles near the large irregular GSR particles often show the same elements and elemental ratios as the larger GSR particle, which suggests an origin from the larger GSR particle.

Many of the large GSR particles adhering to the hair appear disrupted or smeared (Fig. 14). The flattened and distinctively splattered GSR particles that are frequently observed on the monofilaments at 20 cm (as in Figs. 2 and 3), are not observed on the hair shafts. The amount of smearing of the GSR particles on the hair can be quite pronounced (Fig. 15). On occasion, however, partial flattening of the contact area with the hair shaft of the spherical GSR particles are observed (Fig. 16). A comparison of the two target types for the different types of GSR particles is shown in Table 1.

Gunshot residue material frequently can be found to penetrate between the hair shaft and scales (Figs. 17 and 18) in samples where the muzzle-to-target distance is less than 40 cm.

The hair samples shot at 50 and 70 cm show, with rare exceptions, GSR particles without indication of modification of the spherical structure.

Gunpowder on Fabric and Hair

Partially burned gunpowder flakes are often seen on the monofilaments and hair up to 50-cm target distance. Backscatter imaging shows these particles are usually distinctive as a result of their being speckled or smeared with GSR metals (Figs. 19 and 21*b*). Varying degrees of monofilament melting in proximity to a partially burned gunpowder flake may be observed (Fig. 20). Many of the gunpowder fragments are found intimately attached both to the monofilaments (Fig. 20) and hair (Fig. 21).

Discussion

Large (>2.0 μm in diameter) GSR particles which impact a target within 40 cm of the muzzle for 9-mm ammunition are often molten at the time of impact. Impact of molten GSR on a surface results in flattening, splattering, or some form of distortion from the usual

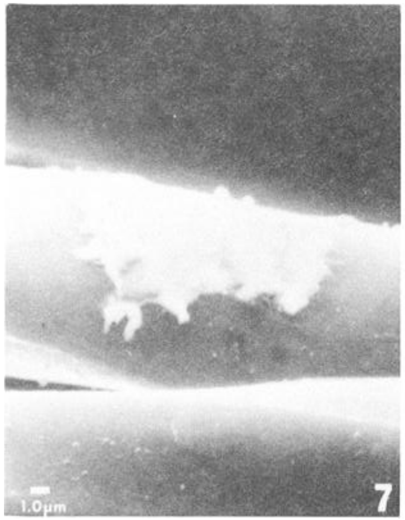

FIG. 7—*Flattened GSR particle with slight deformation of polyester monofilament under particle. Muzzle-to-target distance: 35 cm. Composition: lead-antimony (minor: copper).*

FIG. 8—*Irregular GSR particle with associated deformation of the polyester monofilament. Muzzle-to-target distance: 35 cm. Composition: lead-antimony barium.*

FIG. 9—*Apparent shattered GSR particle on polyester monofilament. Muzzle-to-target distance: 50 cm. Composition: aluminum-barium (minor: lead).*

FIG. 10—Spherical GSR particle partially embedded in polyester monofilament. Muzzle-to-target distance: 70 cm. Composition: lead-antimony (minor: barium).

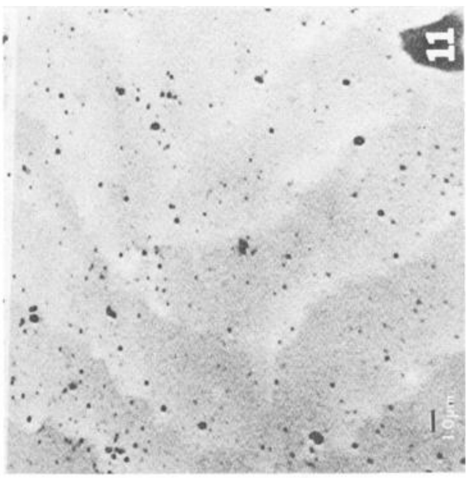

FIG. 11—Backscatter image of small GSR particles on hair shaft. Winchester HPST, muzzle-to-target distance: 10 cm.

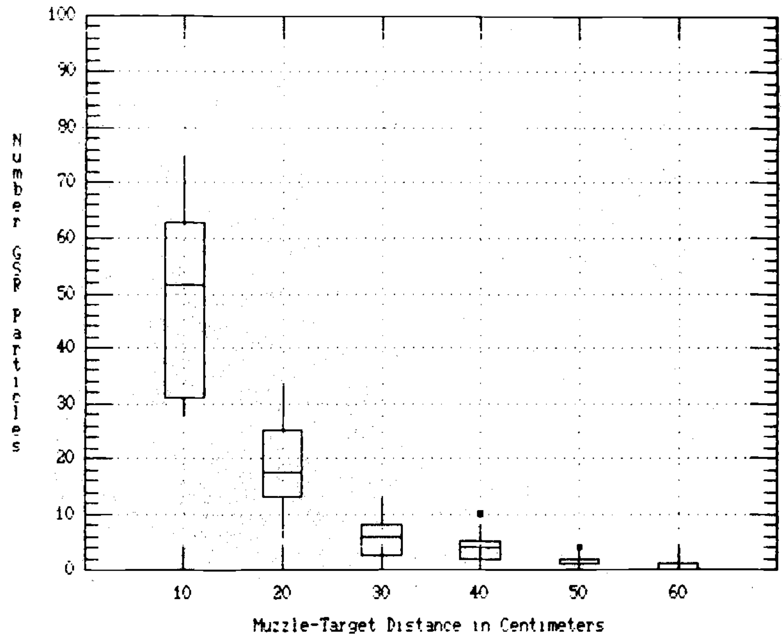

FIG. 12—*Box plots of distribution of GSR particles on hair shafts. Twenty fields at ×5000 were made along hair shafts for the 10- to 60-cm distances of the shots. See Byrkit [7] for a description of the box plots.*

spherical form. Previous workers have failed to recognize that irregular and flattened GSR particles are likely the result of impact of molten or partially molten GSR on the target. Thus, flattened GSR on a target suggests a close-proximity shot. Gunshot residue dusting of targets greater than 50 cm show that particles may actually shatter (Fig. 9) or that adhesion with the fiber surface may occur (Fig. 10). The former observation is likely due to the particles being solid but brittle and the latter likely due to particles being hot at impact and partially melting the polyester monofilament.

Wolten and coworkers [1-3] describe irregular and flattened GSR particles on shooters' hands. Apparently, then, some of the GSR escaping from the breach of a weapon is molten at impact on the shooter's hand.

The fabric and hair samples used different brands of cartridges, which may be the reason for some of the differences observed in both the abundance and morphotypes of the large GSR particles. However, the appearance of the GSR on the hair shaft suggests that movement or fluttering of the hair in the gunshot blast influences the way molten or partially molten GSR attaches to the hair shaft rather than differences of cartridge brands. Movement of the hair in the gunshot blast at 10- and 20-cm target distance, apparently has the effect of scavenging large GSR particles from the blast (Table 1). When molten GSR particles impact the moving hair and its rough surface, the result is smearing (Fig. 15). A stationary target appears to enhance the creation of flattened and splattered GSR particles.

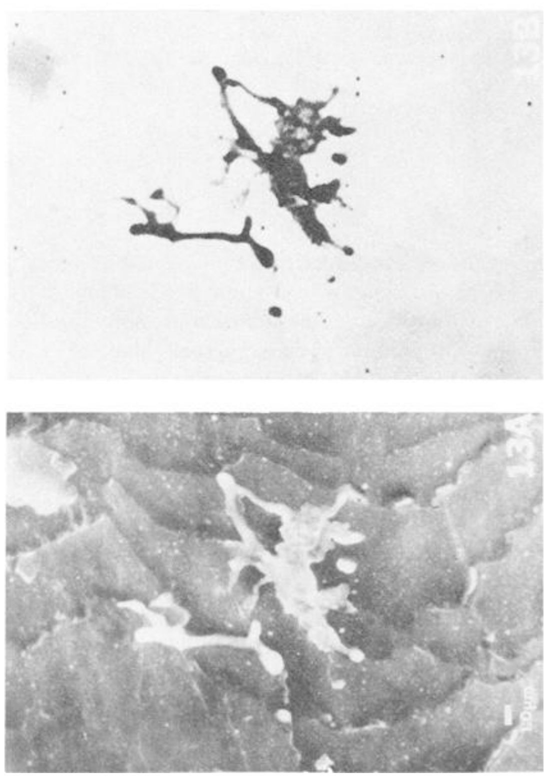

FIG. 13—*Irregular GSR particle on hair shaft. Although this particle is slightly flattened, it does not have a truly flattened structure as that seen in many of the GSR particles associated with the polyester monofilaments. Winchester HPST, muzzle-to-target distance: 20 cm. (A) secondary image; (B) backscatter image. Composition: lead-barium (minor: antimony nickel copper).*

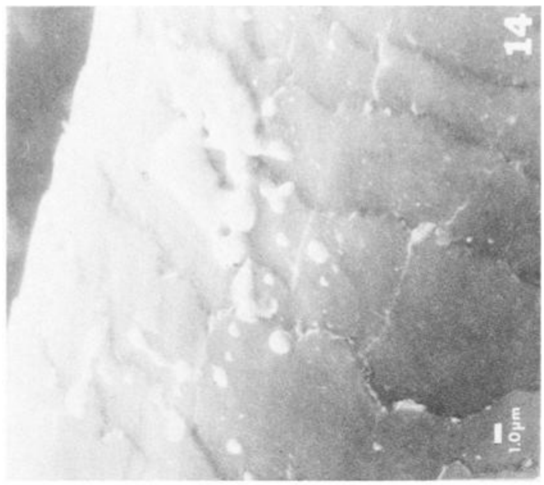

FIG. 14—*Smeared GSR on hair shaft. Winchester HPST, muzzle-to-target distance: 30 cm. Composition: barium-sulfur (minor: copper).*

FIG. 15—*Smeared GSR on hair shaft. Winchester HPST, muzzle-to-target distance: 30 cm. Composition: antimony-barium-sulfur-copper (minor: lead).*

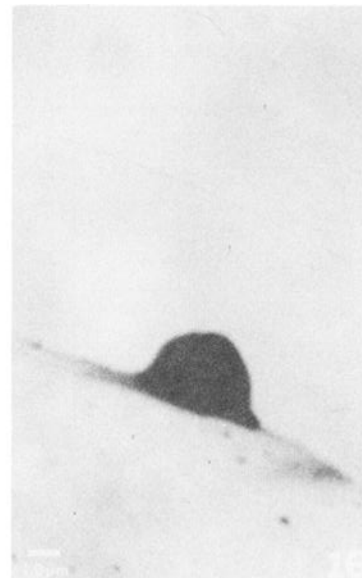

FIG. 16—*Backscatter image of a deformed spherical GSR particle on a hair shaft. Winchester HPST, muzzle-to-target distance: 30 cm. Composition: lead-antimony-copper.*

TABLE 1—*Average number by type of GSR particles above 2.0 μm in diameter for the fabric and hair samples. Twenty fields at ×2000 (5200 μm²/field) for each target distance were assessed from the polyester and the hair samples. General irregular are nonspherical particles which cannot be assigned to the other categories.*

	Target Distances, cm			
	10	20	30	40
Polyester:				
Spherical	NA[a]	0.45	0.70	0.20
General irregular	NA	0.65	0.20	0[b]
Flattened	NA	0.35	0.20	0[b]
Splattered	NA	0.30	0.05	0[b]
Hair:				
Spherical	2.3	2.15	0.40	0.40
General irregular	2.2	6.00	0.25	0.25
Flattened	0	0	0	0
Splattered	0	0	0	0
Under scale	0[b]	0[b]	0.10	0[b]

[a] NA = fibers are so coated with GSR that these particle types cannot be assessed.
[b] Observed in nonquantitative surveys of the sample.

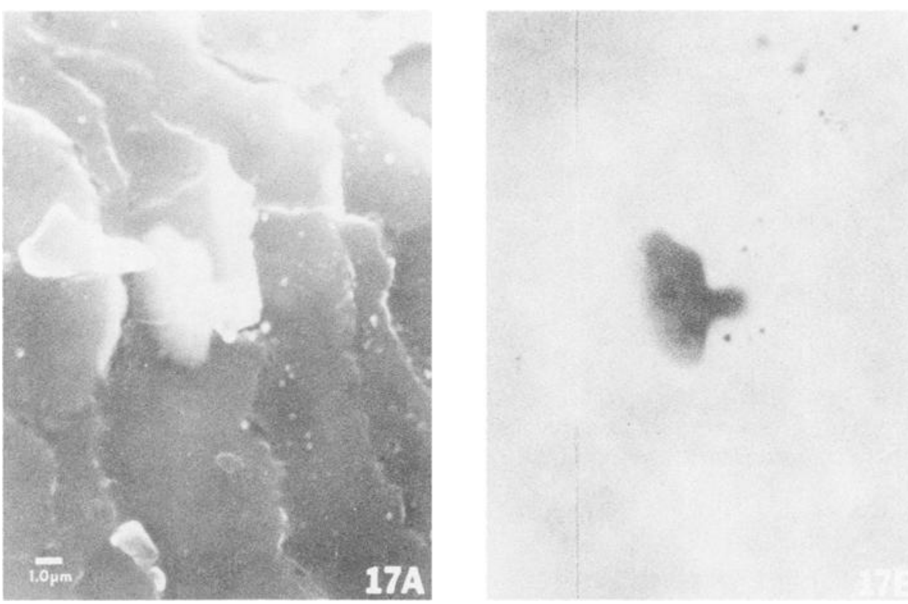

FIG. 17—*Secondary* (A) *and backscatter* (B) *images of GSR particle under a hair scale. Winchester RN, muzzle-to-target distance: 30 cm. Composition: lead.*

Gunshot residue under the hair scales (Figs. 17 and 18), has interesting implications in that the underscale GSR appears to have been initially molten. For this to occur, the hair scales probably were partially lifted from the shaft body in the gunshot blast. Thus, hair interacts with the GSR in the gunshot blast in a manner quite different from the polyester monofilaments.

Form-modified GSR on hair of a victim following an actual shooting may not be similar to that observed in these experiments. However, a close proximity shot where hair is an intermediate target will undoubtedly produce form-modified GSR on the hair shafts and under the hair scales.

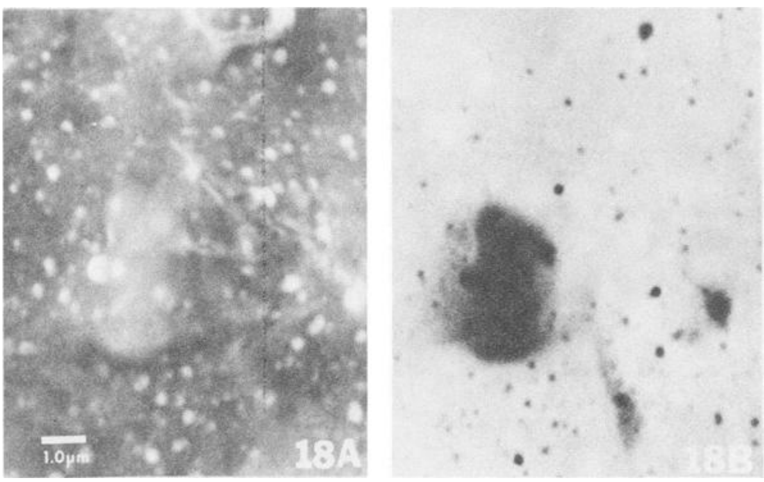

FIG. 18—*Secondary* (A) *and backscatter* (B) *images of GSR particle under a hair scale. Winchester RN, muzzle-to-target distance: 20 cm. Composition: lead-copper (minor: calcium).*

It appears that many of the GSR particles are firmly adhering to the target substrate and would likely remain in place over extended periods of time as long as they are not subject to chemical or mechanical (for example, brushing) attack.

Another way to determine a close range shot is to find adhering fragments of gunpowder. Many of these fragments appear to have been "sticky" when impact occurred and are thus observed intimately associated with the target surface.

Concluding Remarks

The observations of modification of the form of GSR from 9-mm shots described herein will likely have application in shootings with this and other calibers where it is necessary to

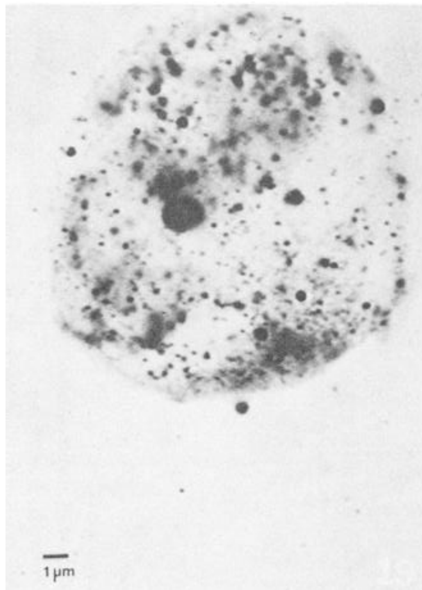

FIG. 19—*Gunpowder fragment on hair shaft with coating of GSR particles on its surface. Winchester RN, muzzle-to-target distance: 30 cm.*

FIG. 20—*Gunpowder fragment almost totally encompassing a polyester monofilament. Monofilament in lower right part of micrograph appears to have sustained heat damage. Muzzle-to-target distance: 10 cm.*

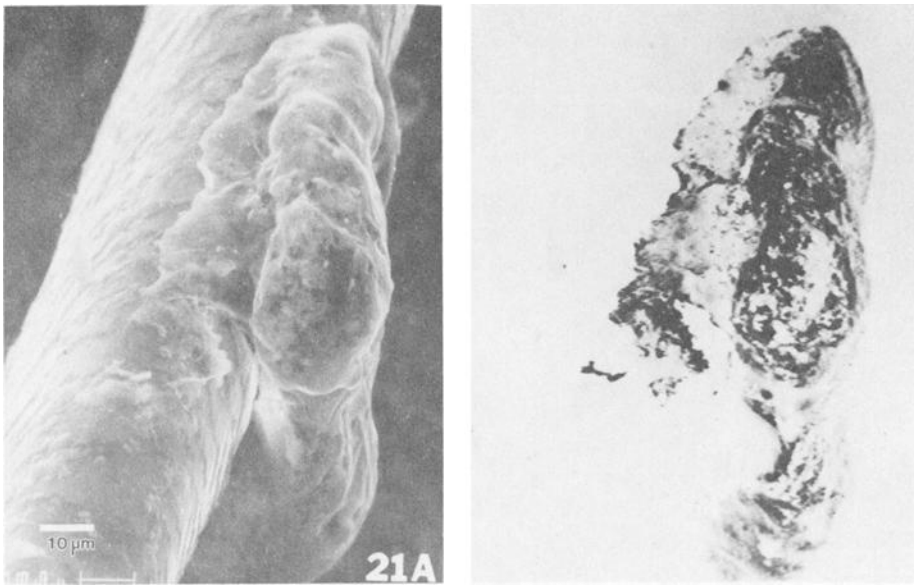

FIG. 21—*Gunpowder fragment adhering to a hair shaft:* (A) *Secondary image;* (B) *backscatter image showing a smearing of GSR metals (dark splotches) over surface of gunpowder. Winchester HPST, muzzle-to-target distance: 40 cm.*

determine a close-proximity shot and the use of other procedures is neither possible nor desirable. Of potential value is the use of hair for GSR analysis in that a badly decomposed body with a head gunshot wound and intact hair may still have the evidence to establish the distance of the shooter. This can be done either by detection of small GSR particles (Fig. 12) or by the form-modified GSR particles. Cases in which fabric is the target may also present such opportunities for the criminalist. However, additional observations both with other calibers and with material from victims of shootings are needed to define more clearly the parameters of the form modification of GSR.

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