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Suicide Reconstruction by Glue-Lift of Gunshot Residue

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ABSTRACT: Based upon the recently developed glue-lift collection of gunshot residue particles for examination in the scanning electron microscope with energy dispersive X-rays, this laboratory has undertaken a research program to determine if reconstruction of gunshot deaths is feasible. Because undisturbed conditions of suicide victims may help in securing unambiguous results and high success rates, the program has been carried out to reconstruct suicides only. Data obtained from 13 firearms suicides and their laboratory reconstruction which involved primarily shotguns and handguns, indicate that reconstruction can be immensely useful to interpretation of the gunshot residue distributions on a suspect's or victim's hands. This reports outlines the basic experiments performed to relate the residue emission from the gun to the deposits found on the firing hand(s) and a description of the reconstruction technique that uses a target to simulate a human body. The technique can determine the specifics of a victim's hand position at the time of firing and which hand was used to pull the trigger. Because the technique is sensitive to the nature of the grasp of the firing hand and of the supporting hand, in the case of a shotgun, it has been possible in all cases to date, to determine which one of the potential eight hand positions existed at the time of shooting.

KEYWORDS: criminalistics, gunshot residues, suicide, glue-lift, scanning electron microscopy with energy dispersive X-rays (SEM-EDX), crime reconstruction

Nomenclature and Abbreviations

The following terms are used in this paper: full-GSR—residues containing all three characteristic elements (lead, antimony, and barium); binary-GSR—residues containing any two of these elements; and mono-GSR or monomers—residues containing only one element. Whenever possible the hand positions are expressed in abbreviated forms: T—trigger; M—muzzle; 1→—trigger oriented away from body; 1←—trigger oriented toward body (shotgun and rifle); ⊥—trigger down (handgun); R—right hand; L—left hand; R_{open}—opened right hand; R_{closed}—closed right hand; B—back of hand; P—palm; and so forth; Dist.—distance; M-L—distance of left hand from muzzle when left hand is on muzzle (shotgun or rifle); M-R—distance of right hand from muzzle when right hand is on muzzle (shotgun or rifle); L-Support—gun supported by left hand; No L-Support—not supported by left hand; Th—Thumb; Th↑—thumb erect; Th↓—thumb down; TR_{open}—right hand forefinger on trigger, opened

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grasp, that is, thumb erect; and TR_{closed}—right hand forefinger on trigger, closed grasp, that is, thumb down.

Introduction

Depending upon its structure and mechanics, a firearm produces certain characteristic effects such as firing pin impressions [*1,2*] and bullet markings [*3*]. The pattern of powder residue emitted from a fired gun is also invariant under controlled conditions of the gun [*4*]. This pattern can be used to estimate the approximate muzzle-to-target distance from the area and density of powder residue on a target [*5,6*]. These characteristics illustrate how guns have potential to aid in reconstruction of criminal events. In this report gunshot residue (GSR) particles will be used to assist in reconstruction of firearm suicides.

Because GSR particles are literally blasted onto exposed areas of firing hands along with the powder discharged at the instant of firing and because the GSR particles that settle from air are negligible [*7,8*], we propose that the variation in the GSR distribution on the shooter's hands can be applied to reconstruction of the hand positions on the gun at the time of shooting. This proposition stemmed from a previous observation that the areas of a firing hand showing the highest density of GSR are very much dependent on the type and condition of the gun and on the nature of the shooter's grasp of the weapon (see Fig. 1 in Ref *10*). Because the amount of residue on the firing hand declines sharply with physical activity [*7,9*], the present research has been directed toward reconstruction of suicides only. Data has been collected from five shotgun suicides, seven handguns suicides, and one rifle suicide, and their reconstruction has been done by a new technique.

Scanning electron microscopy with energy dispersive X-rays (SEM-EDX) has been applied to collection of GSR by glue-lift [*10,11*], developed earlier to overcome many of the difficulties associated with the search for GSR with the SEM-EDX.

Previous studies of firearm suicides using neutron activation [*12*] and photoluminescence [*13*] have indicated that the concentration distribution of GSR elements on a suicide victim's hands rarely conforms with the corresponding distribution on a test shooter's hands if the gun is test-fired in the normal shooting manner. Early in the present work this difficulty was also experienced in correlating the GSR counts from a victim's hands with those from a test shooter's hands. This discrepancy can be alleviated by considering two points in the design of the shooting experiment: (1) the gun structure, the grasp and position of the firing hands on the gun, and the orientation of the trigger toward or away from the shooter's body, all influence the GSR distribution on the firing hands and (2) because a victim's body acts as an intervening barrier, some muzzle residues may rebound. The support hand on the muzzle may show a dense deposit of GSR depending upon the closeness of this hand to the bullet entrance in the body. Hereafter, in this paper "hand positions" will be used to mean collectively the grasp and position of the trigger hand, the muzzle supporting hand, and the orientation of the trigger. By "reconstruction" of a suicide we mean identifying the "hand positions."

Examination of three different positions of a shotgun suicide in Fig. 1 shows that the hand positions are invariant. Since the hand positions have no bearing on the body positions one cannot reconstruct these body positions from GSR distribution on hands. One can simulate the victim's body with a vertical barrier which the shot can easily penetrate but from which the residues may rebound on to the hands. The test shooter can thus duplicate all the hand positions and still do the shooting safely in a standing position holding the gun against the barrier. If GSR are collected immediately after firing, the GSR distribution can potentially be used as the shadowgraph of a hand grasp. Additionally, a more consistent amount of GSR particles may deposit on the hands if the gun is cleaned before each firing. In theory, therefore, one should be able to reconstruct the hand positions at the time of shooting. This hypothesis clearly suggests the necessity of a total of four GSR collections, namely, from the back and palm of each hand of the suicide victim and of the test shooter.

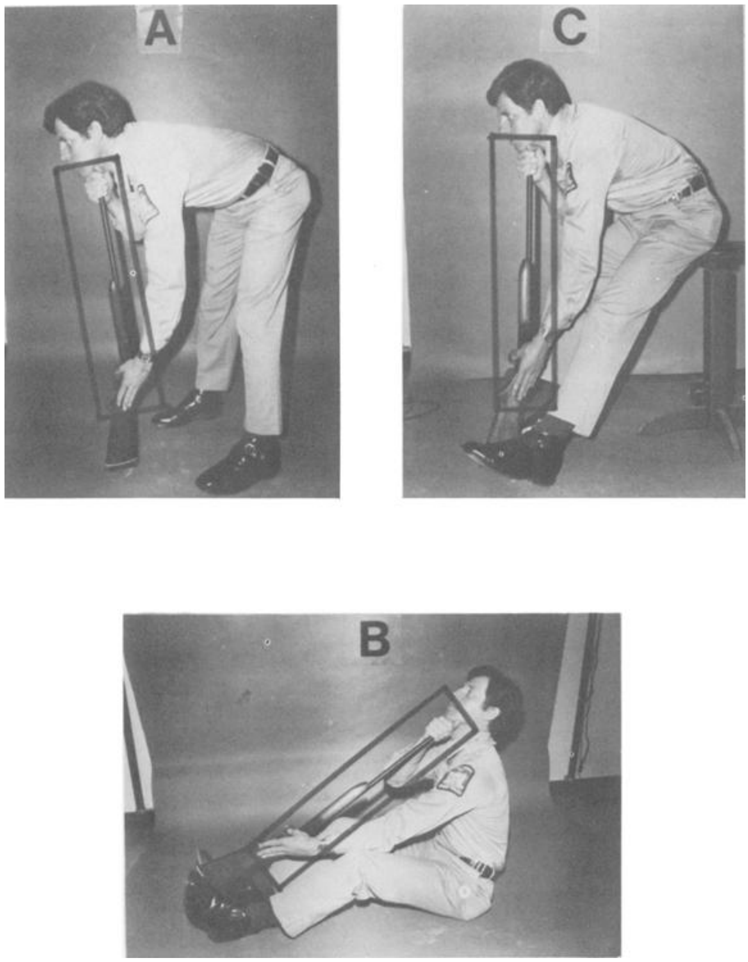

FIG. 1—*Three positions of a shotgun suicide. The body positions in* a-c *give the same GSR distribution on hands because of the same grasps as shown within each rectangle.*

Materials and Methods

Collection

The GSR were collected from four specific areas (Fig. 2, dotted lines) of hands by trained field investigators who kept each GSR kit in a clean place (for example, glove compartment) of their car. The sealed kit was opened only at the crime scene. The kit was resealed immediately after the collection. Proper precautions were taken to avoid contamination and transfer of residue particles. The sealed GSR kit, victim's gun and ammunition, and brief information on each suicide case were submitted to the laboratory.

Case Information

The circumstances of 13 suicide cases are listed in Table 1. Victim 4 was an older female. The rest of the victims were adult men. None of the victims had occupations that might con-

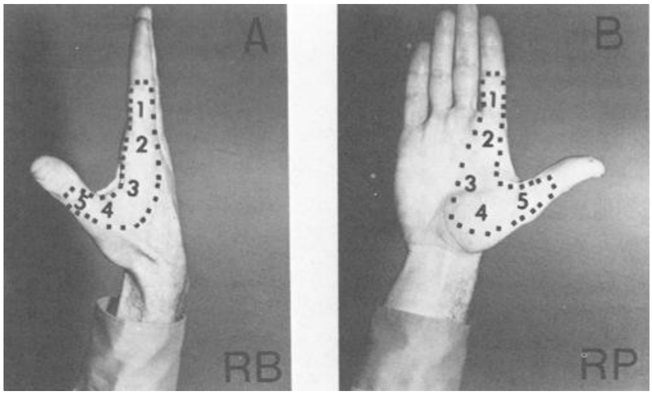

FIG. 2—*Areas of right hand, back of hand* (a) *and palm* (b), *used for GSR collection. The residues were collected by five touches* (1 to 5) *without retouching the same spot. Identical areas of left hand are used. Because the fingertips extending upto the first or second joints (for example, forefinger with handgun: thumb with shotguns and rifles) make contact with trigger, these areas are avoided in GSR collection.*

tribute contaminants. Each victim received only one shot to the body. Victim 11 first shot a dog and then shot himself. Victim 12 used a reloaded cartridge. Unfired reloaded cartridges obtained from his possession were used in test shootings. Unused ammunition found with each victim was used in most test shootings. Stock ammunition of the same brand was used only when there was insufficient ammunition collected from each victim's possession. When a victim was pronounced dead at the scene, the residues were immediately collected. Each agency was advised to take a photo of the crime scene in color that would include the undisturbed victim and the gun. Enlargements were also requested if the victim's hand indicated blood splatter and visible deposits caused by gun powder and so forth.

Search Procedure

Each carbon disk was peeled off its supporting thimble with a scalpel and then mounted with a small amount of conducting adhesive on a 13-mm diameter aluminum stub. After each examination in the SEM-EDX (AMR 1000, EDAX 707A), the carbon disk was replaced in the kit. The aluminum stub was washed in methanol, dried, and reused. Four circles (diameter 1.5 mm) were marked on a glue-lift disk with the sharpened rim of a retracted ball-point pen and the GSR particles were searched for within these boundaries by backscattered electrons [*14*]. They were identified by their characteristic elements (lead, antimony, and barium) [*15-19*] and their condensate morphologies, that is, smooth sphere, nodular spheroid, irregular spheroid, peeled oranges, and hollow spheroid [*10,11*]. When the density of GSR was too great (1000 to 2000 particles/circle), the particles were marked in several sectors of each circle, each sector being photographed at a magnification of 500 to $\times 1000$. Energy dispersive X-ray analysis was performed with the partial field. The magnification required was at least $\times 10\,000$ when the size of particle was about 2 μm. For particles of 20 μm in size and above a magnification of 1000 to $\times 5000$ was sufficient. GSR particles smaller than 1 μm were examined at magnifications of 50 000 and $\times 100\,000$. The other details of X-ray analysis have been reported earlier [*11*].

The GSR particles were tabulated according to their elements, sizes, and morphologies. The counts in all sectors of a circle were added to obtain total GSR particles in this circle. Because of fairly uniform particulate distribution, the GSR counts in four circles were added to obtain the distribution density (ρ) of GSR, or the number of particles per 7.1-mm^2 area of a

TABLE 1—*Information on suicides and GSR tests: handguns (1 to 7), shotguns (8 to 12), and rifle (13).*

Victim	a. gun; b. ammunition; c. bullet entrance; d. condition of victim's hands; e. how victim's body was handled before GSR collection; f. crime scene (indoors/outdoors); g. place of GSR collection; h. victim—right- or left-handed; i. shelf life of GSR kit; and j. delay in GSR collection (approximately) in hours
1	a. .22 cal. H & R model Hammer revolver; b. 22 long-rim-fire (150 grain) Fed.; c. right temple; d. dry and clean; e. not disturbed nor moved; f. indoors; g. crime scene; h. right-handed; i. 4 months, 7 days; and j. $11\frac{1}{4}$ h
2	a. .357 S & W, Model 28-2 revolver; b. .357 magnum (jacketted) S & W; c. right temple; d. dry and clean; e. not disturbed nor moved; f. indoors; g. crime scene; h. right-handed; i. 2 months, 13 days; and j. $2\frac{1}{2}$ h
3	a. .38 special S & W, Model 12 revolver; b. .38 special S & W (jacketted); c. right temple; d. dry and clean; e. not disturbed nor moved; f. indoors; g. crime scene; h. right-handed; i. 3 months; and j. $8\frac{1}{2}$ h
4	a. .38 special S & W, model 36 revolver; b. Remington .38 special round nose lead; c. right temple; d. dry and clean; e. transported to hospital with hands bagged and arrested; f. indoors; g. hospital morgue; h. right-handed; i. 6 months; and j. 19 h
5	a. .357 Ruger Blackhawk revolver; b. R & P .357 magnum (jacketted); c. right temple; d. dry and clean; e. transported to hospital—hands not bagged nor arrested; f. indoors; g. hospital morgue; h. right-handed; i. 4 months, 7 days; and j. 14 h
6	a. .22 cal. H & R model 929 revolver; b. .22 long rifle caliber CCI stinger; c. right temple; d. dry and clean; e. not disturbed nor moved; f. indoors; g. crime scene; h. right-handed; i. 5 months, 20 days; and j. 4 h
7	a. .38 cal. S & W model 10 revolver; b. .38 special S & W (jacketted); c. right temple; d. dry-black deposit on left-hand back; e. not disturbed nor moved; f. indoors; g. crime scene; h. right-handed; i. 5 months, 15 days; and j. $2\frac{3}{4}$ h
8	a. 20 gauge Savage/Stevens, model 940, single-shot hinge frame shotgun; b. CIL 20 gauge $2\frac{3}{4}$ in. #4 shells; c. neck under chin; d. left hand wet in blood: right hand contained patches of black powder; e. not disturbed nor moved; f. indoors; g. crime scene; h. right-handed; i. 2 months, 21 days; and j. $2\frac{3}{4}$ h
9	a. 16 gauge H & R, model 158, single-shot hinge frame shotgun; b. 16 gauge slug (Peters); c. left chest; d. dry but burried in snow; e. disturbed by ambulance volunteers; f. outdoors; g. crime scene; h. right-handed; i. 4 days; and j. 2 h
10	a. 16 gauge Ithaca, model 37, pump action shotgun; b. 16 gauge $2\frac{3}{4}$ in. Remington #4 shells; c. mouth-front of face; d. left hand splattered with blood and right hand dry; e. transported to hospital—hands not bagged nor arrested; f. indoors; g. hospital morgue; h. right-handed; i. 1 month, 2 days; and j. 2 h
11	a. 12 gauge Ithaca, model 37 pump action shotgun; b. Remington $2\frac{3}{4}$ in. magnum, 12 gauge 4-$1\frac{1}{2}$ shells; c. middle of chest; d. dry blood on both hands; e. not disturbed nor moved; f. outdoors; g. crime scene; h. left-handed; i. 13 days; and j. 4 h
12	a. 12 gauge Remington, model Hammerless, hinge frame shotgun; b. Alcan 12 gauge $2\frac{3}{4}$ in., $7\frac{1}{4}$ shotgun cartridge; c. middle of chest; d. dry and clean; e. not disturbed nor moved; f. outdoors; g. crime scene; h. right-handed; i. 14 months; and j. $3\frac{1}{6}$ h
13	a. Springfield Cal., Model 760, Remington 30.06 pump action rifle; b. 30-06 Springfield cal., Fed. cartridge; c. front of temple (forehead); d. dry and clean; e. moved to hospital with hands bagged and arrested; f. indoors; g. hospital morgue; h. right-handed; i. 8 months, 11 days; and j. $5\frac{1}{4}$ h

collection disk. This distribution included all GSR spheroids each of which may contain one, two, or all three characteristic elements of GSR.

Gun Cleaning

The victim's gun and ammunition were routinely examined to determine if it was safe to perform several reconstructive shootings. Since GSR remaining in a gun from a previous firing are released unequivalently in the subsequent firings and because it was unknown if the victim had fired a cleaned gun prior to the fatal shooting or if his hands had acquired residues by handling a fired gun, a procedure requiring routine cleaning of the victim's gun before each reconstructive shooting had to be introduced. The importance of the use of precleaned guns is that one is able to estimate by a comparison of the GSR densities if the suicide victim's hands have had excess residues over the amounts obtained from the test shooter's hands. The presence of these excess residues on the victim's hands was the indication that he used an unclean gun. Since gun cleaning oils and grease retain residues, the barrel, cylinder, magazine, and trigger chamber were all blown with air from an air duster. The exterior and the accessible areas of the interior of the gun (for example, barrel, cylinder, and so forth) were dry-cleaned with pieces of gun cleaning tissues or lint-free cloths soaked in methanol. Because methanol is volatile and removes grease, a gun was usually made ready for a test-firing within 10 min. Test shots showed that the procedure effectively removed contaminating GSR particles.

Reconstruction

The structure used to simulate the body of a suicide victim was a foam pad about 0.6 to 7.6 cm thick mounted on corrugated cardboard 84 by 30.5 cm (Fig. 3). The foam pads were cut from rolls purchased from an upholstery store. The corrugated cardboard containing the foam pad was affixed to a rectangular wood frame (Fig. 4). The frame was well supported from the back and mounted on a wheeled cart. A hard wound area such as the temple was simulated with a foam pad 6 to 9 mm thick. A foam pad as much as 64 to 76 mm thick was used to represent a soft wound area, for example, abdomen, under chin, and so on. Whenever necessary a pair of foam pads, each 38 by 25 by 7.6 cm were used at a desired inclination to represent the body of a victim. The foam pads were affixed to the cardboard with Scotch® brand 465-transfer tape. Fresh cardboard and foam pads were used for each reconstructive shooting.

The reconstruction required essentially clean hands of all persons involved (see Ref *10* for hand cleaning procedure). The procedure for reconstructive shootings is shown in Fig. 5*a*–*c*. The GSR were collected immediately after each firing. These GSR kits were freshly prepared.

To estimate the distance of the support hand from the muzzle of a shotgun (or rifle), several test shots were performed with this hand at various distances from the muzzle (see Fig. 5*b* and *c*). The shortest distance used was about 25 mm and the longest was about 46 cm. The density data were then extrapolated to zero distance. Such extrapolation was necessary in Case 8 since the support hand was presumably in contact with the wound entrance, that is, at the muzzle. Because placing a hand within about 15 cm of the muzzle is inadvisable, flexible plastic hands were made. These were made out of precleaned plastic gloves by inserting cotton balls wrapped around clothes hanger wire into the plastic fingers. Each wire was precut to the length of the corresponding finger upto the wrist except the wire for the middle finger, which was 61 cm long. The glove was sealed at the bottom. The specific grasp and position of this "hand" was created by twisting the wires around the muzzle and then holding the structure from a distance with the long wire from the middle finger. Typically the reconstruction of a shotgun (or rifle) suicide required 8 to 16 test shots. With handguns the number of test shots was two to six. At least two additional shots were made to reproduce each reconstruction.

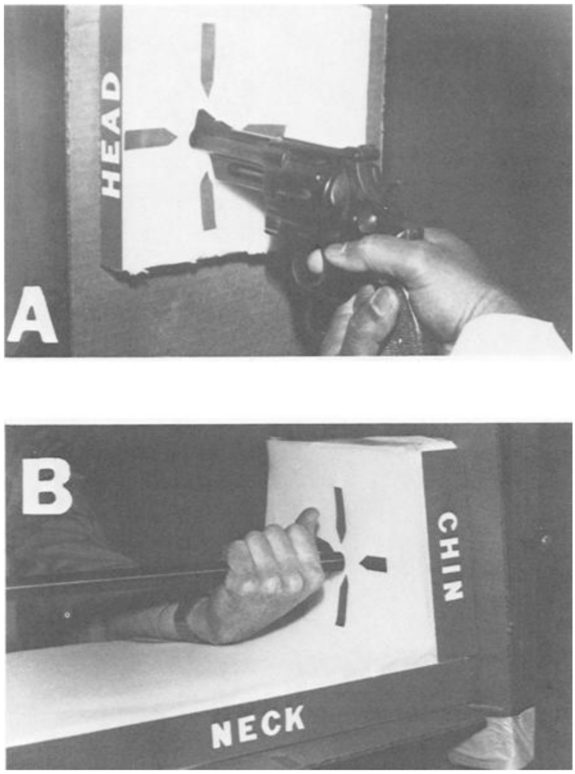

FIG. 3—*Foam pads on corrugated cardboard used to simulate target:* (a) *hard wound, for example, right temple (foam thickness ≤ 1 cm);* (b) *soft wound, for example, under chin (foam thickness ≤ 7.6 cm).*

Results

Reconstruction Criteria and Conditions

Reconstruction of firearm suicides would be impossible if GSR deposition on firing hands varied randomly from one firing to the next. It is suggested here that the random variation in GSR counts previously reported may result from not cleaning the weapon prior to each firing. With a cleaned gun, reproducible particle counts can be obtained from single firings, providing that all residue spheroids in the search area are taken into account (Table 2). The range of particle diameter was 0.2 to 55 μm. The residue spheroids containing one, two, and three elements all contributed to the interpretation of how the gun was held. This criteria, which formed the basis of the present studies, is termed the "density distribution" of GSR.

Although Table 2 presents results with only handguns, the results with shotguns and the rifle of Victim 13 all showed that the value of ρ for each collection and the total for four collections remained fairly constant in single firings. The standard deviation (σ) increased if the gun was not cleaned. Several test shots have shown that residues on the gun from previous shots can be transferred to the hands on contact. This increases the value of ρ on this hand. Furthermore, residue particles that accumulate in the interior of a gun from previous firings are blown off rather irregularly in subsequent firings. This enhances the residue deposit on the back of the firing hand in variable manner. With cleaned handguns the standard deviation (σ)

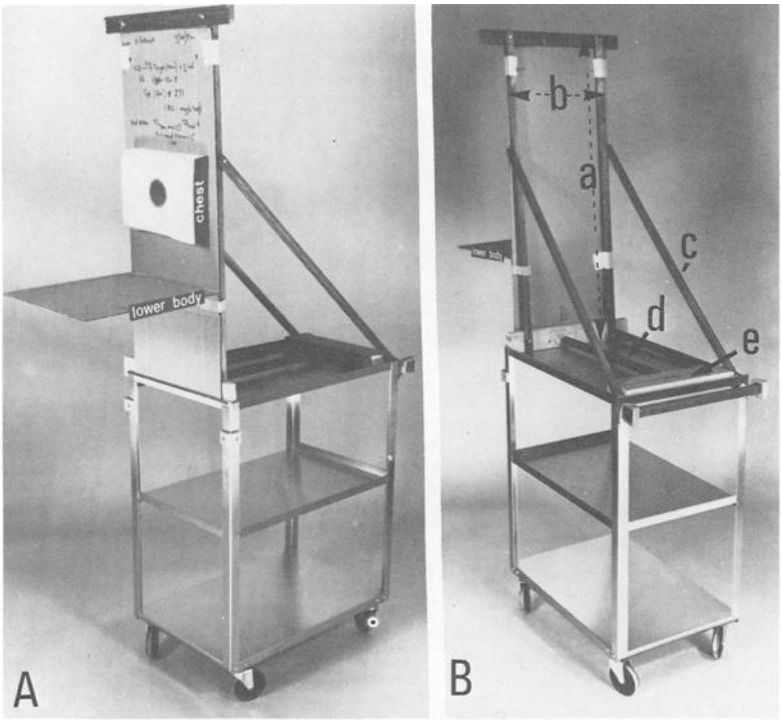

FIG. 4—*Wood frame supporting the foam target on a 70.5 by 41.3 by 81-cm stainless steel cart. Dimensions:* (a) *86.4 cm;* (b) *32 cm;* (c) *84 cm;* (d) *51 cm; and* (e) *33 cm.*

of collection from both hands of a shooter was about 4% or less except in one case (#6) in which σ reached a maximum of 8.5%. The value of σ with shotguns and a rifle (#13) was about 10 to 12%. For all types of guns, the value of σ for a particular collection (for example, RB) was much less variable than the composition of the particles, sizes, and morphologies of particles. This finding was also supported by the results of test firings without an intervening barrier placed at the muzzle [*8*]. The data in Table 2 did not permit evaluation of the influence of increasing caliber because no two victims' ammunition nor weapons were similar. Yet the reproducibility of GSR counts clearly suggests that density (ρ) distribution of GSR is a characteristic function of the type of gun, condition of gun, and the ammunition.

Variables Affecting GSR Distribution

Reconstruction relies greatly upon an understanding of how the density of GSR is influenced by potential variables. Some of these variables have been collectively called the "hand positions," in Table 2. All test firings were performed in an indoor range. The gun structure and determination of the emission ports of a gun were also important considerations.

The GSR deposits on the trigger hand are mainly breech deposits. They are blasted through openings around the breech mechanism and ejection port of pistols and certain types of shotguns (for example, pump action, semi-automatic, and bolt action) and rifles. With hinge frame shotguns, residues escape both from the breech and the gap behind the breech called the hammer-cut. With revolvers, residues escape from the gap at the rear of the cylinder, from the gap between cylinder and barrel, and from the hammer-cut.

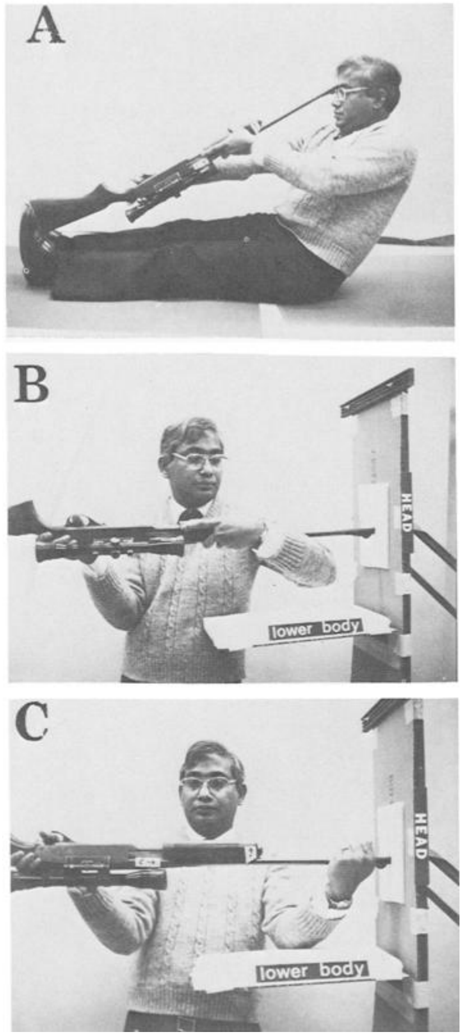

FIG 5—*Reconstruction of potential hand positions:* (a) *rifle (unloaded) in reclined position on floor;* (b and c) *the same gun held against a target, keeping the muzzle hand 46 cm* (b) *or 11.4 cm* (c) *from the muzzle.*

Four main variables seem to influence the breech deposits and the muzzle deposits on hands. These are: (1) proximity of hand(s) to emissive port(s), (2) hand grasp or area of hand exposed to residue gas, (3) dampening or retarding of rebound GSR by target, and (4) trigger orientation. The last variable refers to orientation geometry between the weapon and the hands at the instant of shooting. The effect of each variable has been studied.

Proximity of Hand(s) to Emissive Port(s)—It is the proximity of a hand to an emissive port that chiefly determines the amount and the location of GSR on this hand. For instance, if the supporting hand is around the cylinder of a revolver and the flash gap is barely open, most residues escaping from the flash gap will tangentially strike the back of the hand. The reconstructive shootings in 7, Table 2 were performed under these conditions. With closed breech

TABLE 2—*Reproducibility of GSR counts by glue-lift collection.*[a]

Gun and Ammo (see Table 1)	Hand Positions	Test No. (One Shot per Test)	ρ (Total No. of GSR particles[b] per 7.1 mm^2) RB	RP	LB	LP	Total Residue Number ρ (RB + RP + LB + LP)	Mean Residue Number per Firing and Standard Deviation (σ), %
1	TR_{open} (no L-support) (Th↑), Forefinger of R on trigger (⊥)	1st	200	183	0	0	383	386 ± 4; i.e. σ = 1%
		2nd	205	185	0	0	390	...
		3rd	201	181	0	0	382	...
2	TR_{open} (no L-support) (Th↑), Forefinger of R on trigger (⊥)	1st	12	22	0	0	34	33.5 ± 0.5; i.e. σ = 1.5% (1st and 2nd firing)
		2nd	11	22	0	0	33	
				GUN NOT CLEANED				
		3rd	27	33	0	0	60	42.3 ± 15.2; i.e. σ = 36% (1st, 2nd, and 3rd firing)
3	TR_{open} (no L-support) (Th↑), Forefinger of R on trigger (⊥)	1st	24	28	0	0	52	51.5 ± 0.7; i.e. σ = 1% (1st and 2nd firing)
		2nd	25	26	0	0	51	
				GUN NOT CLEANED				
		3rd	33	35	0	0	68	57 ± 9.6; i.e. σ = 17% (1st, 2nd, and 3rd firing)
4	Same as in 2	1st	136	124	0	0	260	252 ± 8; i.e. σ = 3%
		2nd	112	132	0	0	244	...
		3rd	120	128	0	0	248	...
5	TR_{closed} (L-support) Dist. R to L = 7.6 cm, Forefinger of R on trigger (⊥)	1st	254	48	44	54	400	418 ± 18; i.e. σ = 4.3%
		2nd	273	60	40	63	436	...
		3rd	261	55	41	56	413	...
6	TR_{closed} (no L-support), Forefinger of R on trigger (⊥)	1st	18	0	1	0	19	17.5 ± 1.5; i.e. σ = 8.5%
		2nd	16	0	0	0	16	...
		3rd	18	0	0	0	18	...
7	TR_{closed} (L hand around cylinder, R forefinger on trigger (⊥)	1st	47	0	2184	80	2311	2265 ± 46; i.e. σ = 2%
		2nd	49	4	2095	81	2219	...

[a]See Nomenclature and Abbreviations Section for all abbreviations used in this table.
[b]Full-GSRs + binaries + monomers.

weapons, such as shotguns and rifles, the rebound muzzle residues play an important role in the hand deposit. In fact, the muzzle hand deposit diminished systematically when the distance of this hand from the muzzle is varied (Fig. 6). This information and the other characteristics of muzzle-blast residues [*8*], such as enrichments of bullet (lead) particles, irregular GSR, and so forth were used to distinguish the muzzle hand from the trigger hand.

The density ρ_m of residues on the muzzle hand with shotguns and rifles varies inversely as the square of the distance (S) of this hand from the muzzle (Fig. 6). This gives rise to a straight line plot within a distance which is the "cut-off" distance of rebound residues (Fig. 6). Beyond this distance the rebound residue density on the muzzle hand falls off much more sharply. The curvature in this area suggests that the rebound residue particles may have been attenuated by air drag and gravity. Therefore, if the support hand of the shooter is beyond this cut-off distance, that is, this hand is nearer to trigger than to muzzle, very few muzzle residues will reach this hand. Most of the deposit on the support hand at or beyond the cut-off distance would be due to trigger residues depending upon the closeness of this hand to the openings around the breech mechanism. In fact, Fig. 7 shows that the density ratio of the two hands (ρ_m/ρ_t) diminishes sharply to a minimum at a distance where this ratio ρ_m/ρ_t is less than unity, that is, the muzzle hand density is even smaller than the trigger hand density. This distance was usually 30 to 46 cm from the muzzle exit (see insert in Fig. 7). The trigger hand density ρ_t was fairly unchanged in all firings with individual shotguns and these data have been omitted. (Note: one can evaluate ρ_t with #12 shotgun by substituting the value of ρ_m from Fig. 6 to Curve d of Fig. 7 for a fixed distance [S]). When proper handgrasp (victim's) is used, the trigger hand density ρ_t from a test shooting and the predominance of regular spheroids in this hand

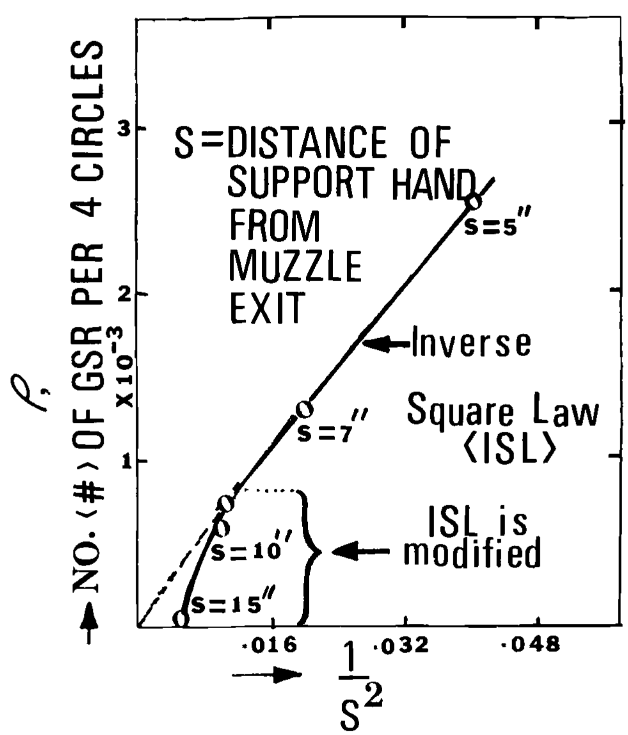

FIG. 6—*Variation of the density* (ρ) *distribution of GSR on muzzle hand with the reciprocal squared distance* (S) *of muzzle hand from muzzle exit. Plot of* ρ *versus* $1/S^2$. *Hand positions* ML_{closed} TR_{open} *(1→) using #12 shotgun. Foam thickness 6.4 cm.*

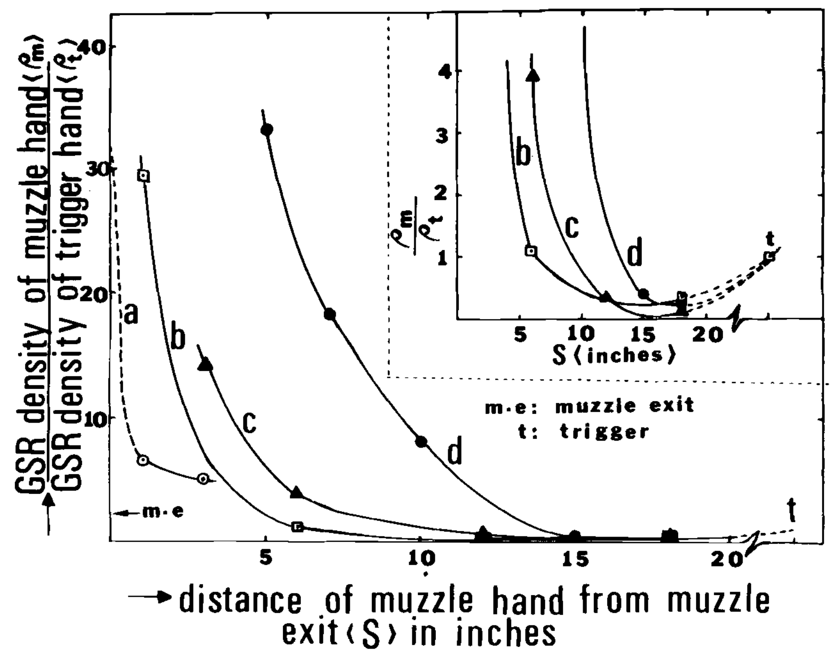

FIG. 7—*Ratio of muzzle hand GSR density* (ρ_m) *to trigger hand GSR density* (ρ_t) *as a function of distance* (S) *from muzzle. Target foam pad 6.4 to 7.6 cm thick. Hand positions:* ML_{closed} TR (I→), *or* MR_{closed} TL *(I→). Changing hands on muzzle did not influence the density of GSR deposits.* (a) *#8 shotgun;* (b) *#13 rifle;* (c) *#11 shotgun; and* (d) *#12 shotgun. Inset shows Curves b, c, and d.*

deposit [8] suggest the hand of victim on trigger. The deposition characteristics (for example, $\rho_m/\rho_t \gg 1.0$) of the remaining hand of the victim must be supportive to this end. Usually if the supporting hand on the muzzle is within the cut-off distance of rebound GSR, this hand deposit ($\rho_m/\rho_t \gg 1.0$) appears to be enriched in lead monomers and irregular GSR particles. Presumably these are bullet particles and bullet-derived GSR. Obviously, these additional features of the muzzle deposit tend to be irrelevant when the supporting hand position on the barrel is nearer to trigger ($\rho_m/\rho_t \leq 1.0$), where the breech deposit predominates on both hands. Therefore for the determination of the muzzle hand position beyond the cut-off distance it was necessary to rely exclusively on the density ratio of the two hands. The two hands of the test shooter on the shotgun were interchanged in alternate findings. This test, which allows the influence of the proximity of hands upon breech deposits, clearly distinguished the trigger hand from the supporting hand of victim (see reconstructions with #10, 11, and 12 shotguns).

Hand Grasp—If the trigger of a handgun was pulled with forefinger and the thumb remained closed (that is, a tight grasp) substantially more residue deposited on the back of hand than on the palm (Table 3 and Fig. 8). If the thumb remained open the residue deposited more evenly on both the back and palm. With certain handguns, dense deposits of residue occurred in the web area between thumb and forefinger. If the open thumb intercepted this deposition the deposit on the palm exceeded the deposit on the back of hand.

Dampening (or Retarding) of Rebound GSR by Target—Because suicide with a gun is usually a contact shot, muzzle blast residues are partially absorbed into the wound and partially rebound. The degree of rebounding is influenced by the hardness of the target area. The rebound residues are slowed by scattering in the tissue.

If the target area is soft, such as, under chin, abdomen, and so forth, most rebound residues

TABLE 3—*Effect of hand grasp on GSR distribution: firing of handguns with forefinger on trigger.*

Gun and Ammunition (see Table 1)	No. of Shots	Type of Grasp	ρ (Total Number of Residue Particles per 7.1 mm²) RB	RP	LB	LP	Total Residue on Hand
2	1	(a) open (i.e. Th↑) of R; no L support	12	22	0	0	34
	1	(b) closed (i.e. Th↓) of R; no L support	17	8	0	0	25
3	1	(c) open (same as *a*)	25	26	0	0	51
	1	(d) closed (same as *b*)	24	16	0	0	40
4	1	(e) open (same as *a*)	136	124	0	0	260
	1	(f) closed (same as *b*)	128	72	0	0	200

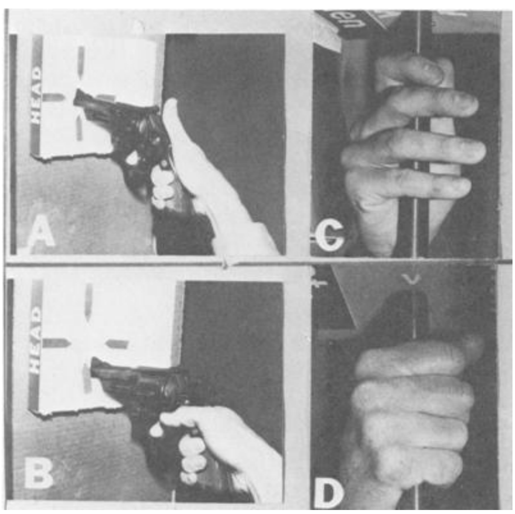

FIG. 8—*The effect of hand grasp on GSR distribution on firing hands:* (a) *open (thumb erect);* (b) *closed (thumb down);* (c) *open supporting hand; and* (d) *closed supporting hand.*

are slowed and take zig-zag trajectories beyond the cut-off distance. The thickness determines the degree of dampening of these residues. The spread of these residues is limited. If the support hand on the muzzle is within the cloud of these residues, a heavy deposit would result.

If the target area is hard, such as the head, the rebound residues are scattered rather widely. This interpretation was in strong agreement with the quantitative data of GSR distribution of all cases in this report and their reconstructions. Table 4 presents a comparison between results obtained with a mounted foam pad and with cardboard only. With the cardboard only the residue density on the muzzle hand back was about one fifth of the residue density with the foam pad.

Trigger Orientation—The orientation of shotguns and rifles can vary widely in a suicide. It is limited by the gun structure and length, however the two most likely trigger orientations are trigger turned away from body (I→) or trigger turned toward body (I←). Theoretically, handguns can also be similarly oriented however, the present studies suggest that trigger toward the body, or trigger down (⊥), was the case with all handgun victims.

The influence of trigger orientation on density (ρ) distribution of GSR on firing hands is shown in Fig. 9, using the data of Case 9 and its reconstruction. Eight test shots were performed, using a specific grasp (open and closed) of the muzzle hand while the trigger hand was always open, and maintaining a specific orientation of trigger. Also, the hands of the test shooter were interchanged. The relative proportions of the four residue collections from the victim's hands agreed only with the four collections from the first test shot. Therefore the hand positions in (1) constituted the most probable reconstruction of this suicide, despite a modest retention (approximately 48%) of residues of the victim's hands. Note:

$$\text{retention of residue} = \frac{\text{total residues from victim's hands}}{\text{total residues from reconstruction}} \times 100$$

Notice that GSR deposit on the muzzle hand changed very systematically with the change in trigger orientation. The orientation (I→) away from body produced three- to four-fold more residues on muzzle hand than did the orientation (I←) toward body. This effect was neither influenced by the target thickness and geometry, nor was it related to variations in the tightness with which the barrel was held against the target. So it is suggested that the immediate discharge of muzzle blast residues is probably assymmetric. In fact in three cases (#8, 10, and 13) the trigger orientation was determined independent of any information of victim's hand positions on the gun. The photos of the crime scenes confirmed later on the consistency of these determinations.

Potential Hand Positions

As may be seen in Fig. 9, the variables in suicide with a shotgun and its reconstruction involve both hands (trigger and muzzle) and two kinds of grasp (open or closed) per hand. When these variables are taken into account, a total of 2^4 or 16 test shots become necessary to reconstruct a shotgun suicide. In practice, the data from the four collections from the victim's hands may aid in minimizing the number of test shots. In Fig. 9, the grasp of the trigger hand was kept "open" in eight test firings. This grasp was indicated by the ratio of deposits on the back versus the palm of the victim's right hand. The relatively high ratio of deposits between left hand and right hand of victim also indicated that the left hand of victim might be the muzzle hand. The deposit on the left hand of victim was also enriched (about 88%) in lead monomers.

TABLE 4—*Dampening or retarding of rebound GSR.*

Target Material and Thickness	Shotgun (Table 1)	Hand Positions	ρ (Total Number of Residue Particles per 7.1 mm^2)			
			RB	RP	LB	LP
a. Foam pad; thickness 6.4 cm	8	MR closed TL open (I→) M-R (Dist.) = 2.54 cm	1604	122	166	100
b. Cardboard; thickness 0.3 cm	8	MR closed TL open (I→) M-R (Dist.) = 2.54 cm	300	68	144	98

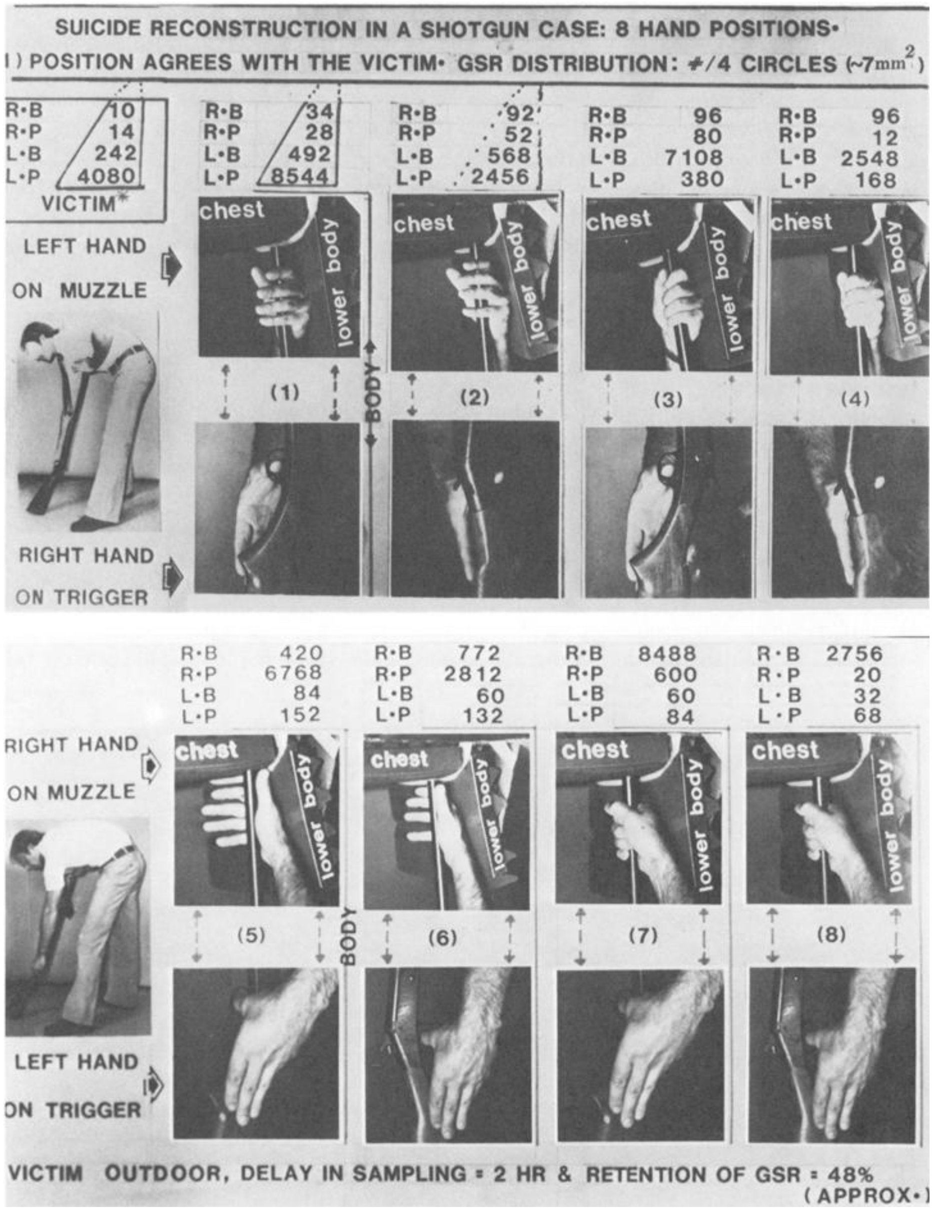

FIG. 9—*Suicide reconstruction in a shotgun case: eight hand positions. One position agrees with the victim.*

Therefore the approach was to use an open grasp of the trigger hand and to test the other variables. This approach has worked well in the reconstruction of the shotgun and rifle suicides. The minimum number of potential hand positions with these long arm weapons was eight. Because each reconstruction was confirmed by two to three additional shots, the level of confidence was enhanced. The total number of shots required with a shotgun would be more than eight if other details of the hand positions were required, such as, the exact finger (thumb or forefinger) on the trigger.

Figure 10 shows two ways that #7 victim could have fired his revolver and two different ways he could have supported the barrel. The residues collected from this victim's hands were: $\rho(RB) = 47$, $\rho(RP) = 3$, $\rho(LB) = 2104$, and $\rho(LP) = 3$, each area of search = 7.1 mm^2. Since the residues on the palms of both hands of the victim were negligible the grasps would have to be closed. The heavy residue deposit (2104 GSR) on the back of the victim's left hand indicated that this hand was either on the cylinder or on the muzzle.

The victim's (#7's) handgun and identical targets (foam thickness 1 cm) were used in four test-firings, keeping potential hand positions of the test shooter on the gun (Fig. 10). These hand positions and the corresponding density (ρ) data of GSR distribution (per 7.1 mm^2 of each disk) were as follows:

a. Right-hand forefinger on trigger (trigger down), closed grasp (thumb down), and left-hand palm around cylinder leaving the flash gap barely open. $\rho(RB) = 47$, $\rho(RP) = 0$, $\rho(LB) = 2184$, and $\rho(LP) = 80$.

b. Right hand same as in *a* but left hand around muzzle (barrel) in contact with the foam target. $\rho(RB) = 87$, $\rho(RP) = 3$, $\rho(LB) = 803$, and $\rho(LP) = 31$.

c. Right-hand thumb on trigger (trigger down), closed grasp, and left-hand palm around cylinder, same as in Fig. 10*a*. $\rho(RB) = 14$, $\rho(RP) = 2$, $\rho(LB) = 2004$, and $\rho(LP) = 84$.

d. Right-hand thumb on trigger (trigger down), closed grasp, and left-hand palm around muzzle (barrel) in contact with the foam target. $\rho(RB) = 23$, $\rho(RP) = 3$, $\rho(LB) = 827$, and $\rho(LP) = 40$.

A comparison between residue deposits from the victim's hands and residues obtained from a test shooter's hands showed that the hand positions in Fig. 10*a* were the most likely ones. The

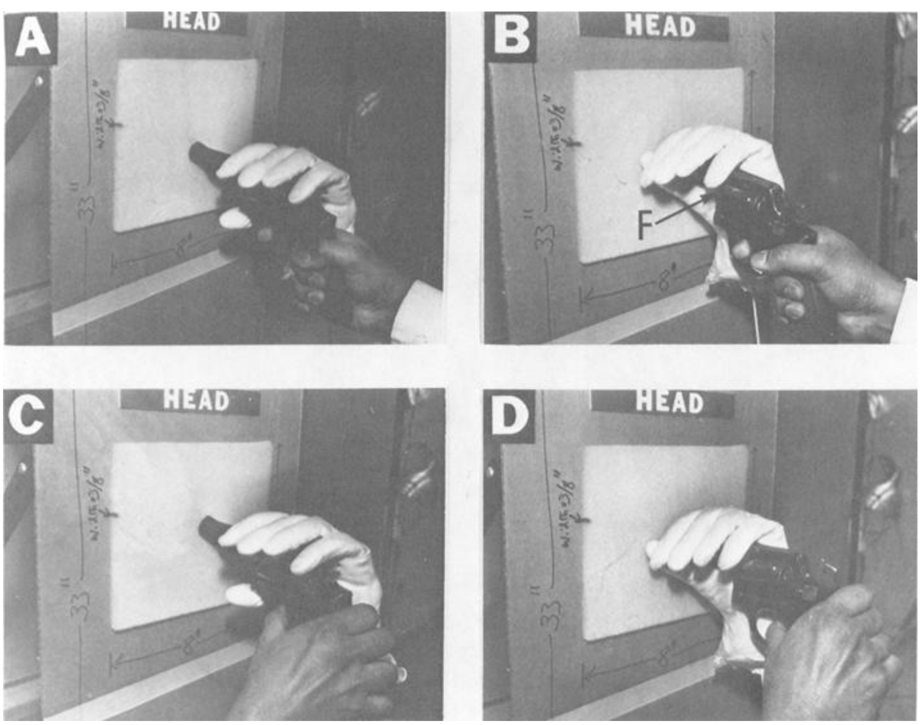

FIG 10—*Four potential hand positions of a handgun suicide (#7). Arrow* F *is flash gap.*

heavy deposit on left-hand back was a result of residues from the flash gap between cylinder and muzzle.

Because the support hand was plastic in those test firings, the relative uptake of GSR on plastic skin was estimated by comparing with several firings with and without a glove on the trigger hand. These test shots were performed in normal firing position without the target at the muzzle and with only the right hand on the gun. The density (ρs) of residues obtained from the back and palm of the trigger hand (no glove) were 208 and 0, respectively. The corresponding values with glove were 200 and 0, respectively. These results showed that the density of GSR distribution were almost equivalent with the bare hand and the plastic hand.

Suicide Data and Reconstructions

Table 5 presents the GSR distribution data on the 13 cases and their reconstructions. The retention of GSR in this table and in Fig. 9 are only approximate estimates. Five handgun cases (#1-4 and 6) were simpler that the rest. In these five the right hand of each victim contained the most residues. The few residues on the left hand of these victims were presumably the contaminating residues (6% of the total per hand) from handling the gun. This derivation has been possible as a result of the use of precleaned guns. The reconstruction of #5 and 7 suggested that the right hand of each victim was on the trigger while their left hand was the supporting hand on the cylinder (#7) or on the right hand (#5). All of these victims were reportedly right-handed. Among the shotgun and rifle suicides, Victims 9, 10, 12, and 13 were right-handed and reconstruction experiments suggested that their right hand was on the trigger. As for the muzzle hand position with the rifle case (#13) the hand position in Fig. 7*c* was the most probable one. The other hand positions (Fig. 7*a* and *b*) were wrong. Victim 11 was left-handed and reconstruction indicated his left hand was on the trigger. Victim 8, according to reconstruction, had his left hand on the trigger although he was known to be right-handed.

GSR Class

It may be of interest to know why the GSR particles collected by glue-lift from the hands of suicide victims and the test shooter have been classified into full-GSR, binary-GSR (or binary), and mono-GSR (or monomer.)

A full-GSR is by elemental composition (lead, antimony, and barium) the same as "unique GSR" of the first category in Wolten et al [*17*]. But according to them, residue particles of other compositions may also be considered "unique-GSR." These compositions are barium, calcium, and silicon plus a trace of lead if copper and zinc are absent and antimony and barium. These types of particles were classified here as mono-GSR and binary-GSR. The class of binary-GSR includes particularly the "characteristic GSR" or "consistent GSR" particles in Wolten et al [*17*]. Bullet particles were included as mono-GSR inasmuch as these were condensate, that is, molten in appearance. Highly irregular and crystalline lead and barium containing particles often arise from human environments [*17*]. There is a chance that such irregular looking particles were initially spheroids, or they have had at least the appearance of condensate, but that they have been subsequently modified to irregular forms because of wetness or perspiration of hands or both. However, this theory has not been proven. Therefore the present approach has been somewhat inbetween, that is, if the majority of "monomer" particles were spheroids and only a few of them were irregular, these were marked "i" in micrographs of the searched area and discounted (Fig. 11). Even regular monomer particles (spheroids) whether they might contain barium, antimony, or lead were disregarded unless full-GSR or binary-GSR were also existent on the same collection disc. The monomer particles had to be included in the present studies mainly because they were present in significant numbers in collections from reconstructive firings. This approach provided a valid comparison and hence

TABLE 5—*Reconstruction of 13 suicides using handguns (1-7), shotguns (8-12), and rifle (13).*

a. Victim b. Reconstruction	ρ (No. of GSR Particles per 7.1 mm^2)				Approximate Retention of GSR, %	Confirmed Hand Position
	RB	RP	LB	LP		
a. 1	172	165	4	0	86	TR_{open} (Th↑) (No L-support) (⊥)
b. Reconstruction	200	183	0	0		
a. 2	8	23	2	0	100	TR_{open} (Th↑) (No L-support) (⊥)
b. Reconstruction	12	21	0	0		
a. 3	24	27	0	0	100	TR_{open} (Th↑) (No L-support) (⊥)
b. Reconstruction	25	26	0	0		
a. 4	144	136	4	4	110	TR_{open} (Th↑) (No L-support) (⊥)
b. Reconstruction	136	124	0	0		
a. 5	50	11	5	9	17	TR_{closed} (Th↓) (L-support, Dist. R-L = 7.6 cm) (⊥)
b. Reconstruction	273	60	40	63		
a. 6	14	1	1	0	89	TR_{closed} (Th↓) (No L-support) (⊥)
b. Reconstruction	18	0	0	0		
a. 7	47	3	2104	3	93	TR_{closed} (Th↓) (L-support around cylinder) (⊥)
b. Reconstruction	47	0	2184[a]	80[a]		
a. 8	8052	624	136	88	100	MR_{closed} TL_{open} (1→). Dist. M-R = 0
b. Reconstruction	8000[b]	600	168	100		
a. 9	10	14	242	4080	48	ML_{open} TR_{open} (1→), Dist. M-L = 8.3 cm
b. Reconstruction	34	28	492	8544		
a. 10	32	100 screwdriver 44	12	28	48 (80% screw-driver)	ML_{open} $TR_{screwdriver}$ (1→). Dist. M-L = 30.5 cm
b. Reconstruction	104	160 screwdriver 56	40	84		
a. 11	12	0	200	223	97	MR_{closed} TL_{open} (1←) Dist. M-R = 30.5 cm
b. Reconstruction	32	0	200	216		
a. 12	64	2	20	3	89	ML_{closed} TR_{closed} (1→) Dist. M-L = 38 cm
b. Reconstruction	61	11	21	7		
a. 13	65	14	197	35	110	ML_{closed} TR_{closed} (1→) Dist. M-L = 11.4 cm
b. Reconstruction	63	11	180	29		

[a]Plastic glove on hand.
[b]Extrapolated from Curve a, Fig. 10.

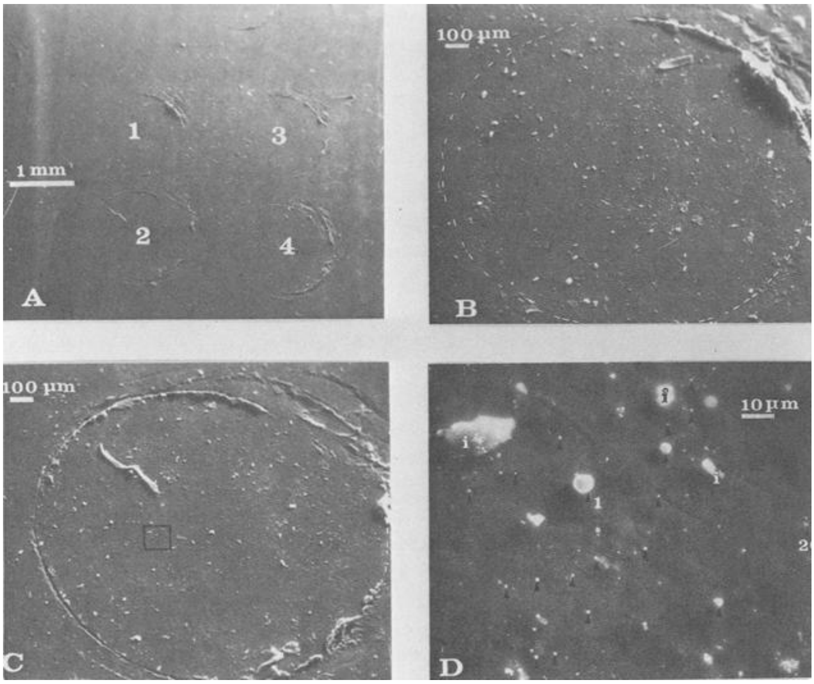

FIG. 11—*Back scattered electron images of GSR from right hand back of Victim 8:* (a) *four circles at a magnification of* ×*18. Circles 1 to 4 contain 2284, 1763, 2105, and 1900 particles, respectively;* (b and c) *Circles 1 and 2, respectively, at a magnification of* ×*65;* (d) *the rectangle marked in* c *magnified* ×*900. This small field contained 20 GSR particles (diameter 0.3 to 6.7 µm).*

a safer analysis. The classification into full-GSR, binary-GSR, and mono-GSR avoided dependence on nonspecific elements (for example, calcium, silicon, sulfur, copper, zinc, and so on). This classification has been important in the analysis of GSR in casework.

Discussion and Conclusion

Since its development, glue-lift collection has been a research tool aimed at improving the credibility of gunshot residue examinations [*6,8,11*]. The technique now is not only being used to confirm suicides but also to make an assessment independent of other types of evidence whether a suspected gunshot death is a suicide, or an accidental death, or a homicide.[2] The density distribution of GSR is able to indicate the hand positions on a gun. The use of precleaned guns has been important to this documentation. Suicide victims were the subjects chosen because they were known to have fired a gun.

Suicide verification using SEM-EDX was also made by Wolten et al [*17,20*]. These authors used "tape-lifts" of GSR from a victim's hands and compared them with identical collections (two) from the hands of a test shooter. The main difference was that the shooter in their experiments shot the victim's gun, without a target backing and with normal positions of firing hands.

Wolten et al were able to confirm 94% of handgun cases (29 out of 31) and 50% of shotgun/

[2]S. Basu and R. W. Horn, "Reconstruction of Shootings by GSR," 1983, unpublished paper.

rifle cases (2 out of 4). But they and other authors [*12,13*] did not specifically address some basic questions that were crucial in their attempt to verify shooting crimes.

The first question is: do guns discharge GSR in a consistent manner in single firings? The answer is yes, in so far as the deposition of GSR on firing hands is concerned (Table 2). Opinions on this position have varied. Matricardi and Kilty [*18*] found variation of GSR counts in single firings. Wolten et al [*20*] reported that "generally the number of particles deposited on the victim's hands at the time of firing is at least equal to that resulting from normal firing when a handgun is used." In a more recent paper Gansau and Becker [*21*] suggest that precleaned handguns produce characteristic patterns of residues on the firing hand depending on the ammunition and the time lapse between firing and sampling. This suggestion was consistent with the earlier observation using the glue-lift technique except that hand grasp and condition of the weapon must also be included among the pertinent variables with handguns [*10*]. None of these reports, however, has considered the mechanics of GSR deposition on firing hands with shotguns and rifles. The results in this report with these guns have significant implications. For example, the data in Figs. 6 and 7 have shown that (a) muzzle blast residues and trigger blast residues may seldom overlap and (b) this allows one to distinguish the muzzle hand from the trigger hand. Trigger hand residues originate from the breeches of the weapon and do not overlap with muzzle blast residues. The overlap of residues from other ports on the muzzle hand depends on the distance of this hand from the ports. Experiments performed for another report [*8*] have shown that even in normal firing situations most residues on the firing hands are from the breech area of the weapon.

The GSR counts in multiple firings do not increase directly with the number of shots because residues on the hand may be partially blown off by subsequent firings. Furthermore, residues in the gun from previous shots are blown from the interior in each firing. The inherent limitation of any "lifting" technique including the glue-lift method is that such multiple firing events can hardly be reproduced.

The manual search rate of GSR in a particular circle was typically from about 15 s to a maximum of 1½ min depending upon magnification or the density (ρ) of GSR on the disks. This time refers to mainly X-ray counting and to movement of the specimen stage. This time did not include photographic time, data keeping time, and recording time. The total area examined on each disk was 7.1 mm^2. Although this area is only 6% of each collection disk, the total number of particles was often large enough for statistical purposes (compare Ref *7*). In this case the variation between circles was much less than the sample-to-sample variation per firing.

The suicides examined in this report involved single gunshot wounds and single firings by each victim except Victim 11. By including one additional test shot (without target) prior to the reconstructive shooting we have been able to confirm the hand positions of this person. (Note: if we had not been informed of this additional firing, reconstruction of this suicide case would have been misleading.) Suicide cases involving multiple gunshots are uncommon [*22*]. Eisele et al [*23*] encountered 3 such cases in a total of 226 suicides. Reconstruction of these complex suicides and reconstruction of suicides in which the person's firing activities before he took the fatal shot are unknown, would be difficult, if not impossible.

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