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Characteristics of Silenced Firearms and Their Wounding Effects

REFERENCE: Menzies, R. C., Scroggie, R. J., and Labowitz, D. I., **"Characteristics of Silenced Firearms and Their Wounding Effects,"** *Journal of Forensic Sciences*, JFSCA, Vol. 26, No. 2, April 1981, pp. 239-262.

ABSTRACT: The rate of seizure of illegally held silenced handguns has risen dramatically in recent years. Despite this, there are apparently no reports of wounds caused by these weapons. The efficiency, in terms of noise reduction, of silenced handguns is largely determined by construction, and homemade weapons are frequently more efficient than their commercially manufactured counterparts. Wounds are likely to be inflicted at either contact or close range. Muzzle imprints are erythematous rather than abraded and disproportionately large for the size of the wound. Close-range wounds frequently exhibit atypical entrances. Examination of wound edges by energy-dispersive analysis of X-rays may demonstrate the presence of unusual elements, sometimes associated with components of the silencer. Also, inspection of recovered bullets with the naked eye may reveal damage indicative of modifications to the barrel or misalignment of the device. With these criteria it should be possible in many cases to support or refute the suggestion that a silenced weapon had been used to inflict a given wound.

KEYWORDS: criminalistics, ballistics, wound ballistics

The National Firearms Act [*1*] defines a silencer or muffler as a firearm. The Code of Federal Regulations [*2*] further defines a silencer as "any device for silencing or diminishing the report of any portable weapon such as a rifle, pistol, revolver, machine gun, submachine gun, shotgun, fowling piece or other device from which shot, bullet, or projectile may be discharged by an explosive, and is not limited to mufflers or silencers

The opinions or assertions contained herein are the private view of the authors and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense. In conducting the experiments described in this report, the investigators adhered to the "Guide for Laboratory Animal Facilities and Care," as promulgated by the Committee on the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal Resources, National Academy of Sciences-National Research Council. Product names used in this publication are for descriptive and identification purposes only and do not imply recommendation or endorsement by the authors or any public or private agencies. Received for publication 12 Feb. 1980; revised manuscript received 21 July 1980; accepted for publication 25 Sept. 1980.

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for 'firearms' as defined." In addition, in most states, state law augments these definitions to a greater or lesser extent.

Up to 1934, no controls existed for silencers, and mail-order devices—many of them Maxims—were common. A few of the original mailing tubes are still in existence. Currently the making, transfer, and receipt of firearms (including silencers) is controlled by the National Firearms Act [3,4]. Under this Act, any of the above actions are unlawful unless preceded by proper application to and approval by the U.S. Treasury Bureau of Alcohol, Tobacco and Firearms (ATF) and payment of the proper tax. Appropriate application automatically brings about proper registration in the National Firearms Registration and Transfer Record. Possession of unregistered silencers is therefore unlawful [5]; all unregistered silencers are subject to seizure and forfeiture, and persons illegally making, possessing, or transferring contraband firearm silencers are subject to arrest and, if convicted, severe penalties. Responsibility for enforcing these regulations is vested in ATF.

Despite these controls, in the experience of one of the authors [6] the number of seizures of contraband silencers has increased dramatically over the years 1969 through 1976. A search by computer of the world medical literature, however, failed to uncover any published cases of wounding in which a silenced firearm was shown to be responsible. Furthermore, there appeared to be no publications dealing with the characteristics of such wounds and in what respects, if any, they differ from wounds produced by conventional firearms.

It seemed improbable to us that the increased number of seizures could occur in the absence of an increase in use, and therefore we concluded that the possibility of a wound's having been caused by a silenced firearm was not routinely being considered, and when that possibility was considered it could not be checked against published material. This study, therefore, seeks to present information on the structure and function of firearm silencers and to establish comparative characteristics for wounds known to have been inflicted in animals by unmodified and by silenced weapons.

Materials and Methods

Sixteen silenced weapons in the possession of the ATF were used. Their nominal calibers included 0.22 in., 0.32 in., 0.45 in., and 9 mm. The silenced weapons were matched to controls, one for each caliber represented. None of the weapons was a revolver.

The efficiency of the silencers was measured by firing each weapon with and without its silencer whenever possible and recording the impulse noise in decibels with an impulse precision sound level meter (Bruel and Kjaer Type 2209). Final noise level was taken as the average of at least six shots. The silencers could not be detached from two weapons (Nos. 816 and 814), and their efficiencies were roughly assessed by comparing their noise levels with those of the control weapons of the same caliber.

The effect of silencers on missile velocity was measured with a computing chronograph (Electronic Counters, Inc., Model 4001). Again each weapon was fired a minimum of six times with and without its silencer whenever possible, and the bullet velocity was taken as the average of these six results. Where the silencers could not be removed, the velocities were measured for the silenced weapon only; no comparison with control weapons was attempted because of the differences in manufacture of the weapons.

Each weapon was fired at a range of approximately 0.3 m (1 ft) into a cotton-packed bullet trap, and the bullets were recovered and examined for gross deformities attributable to the silencers.

For the examination of the wounding characteristics of silenced firearms, pigs had been selected as animal models because of the relative hairlessness of pigskin and the close histologic similarity between pigskin and human skin. The animals used were female

Yorkshire domestic white swine, each weighing between 34 and 45 kg (75 and 100 lb). Surgical anesthesia was achieved by intravenous administration of sodium pentobarbital (approximately 30 mg/kg body weight) by means of an indwelling butterfly cannula in a lateral ear vein.

Each anesthetized animal was washed and lightly clipped, care being taken to avoid damage to the skin. Each weapon in the series was fired into an animal at contact and at distances of 305 and 660 mm (12 and 26 in.). Each animal was shot between four and six times, the shoulder and the hindquarter (with the point of impact lateral and anterior to the wing of the ileum) being used as target areas. The shots were administered as rapidly as possible and each animal was subsequently killed by intravenous administration of more sodium pentobarbital given under the direction of the attending veterinarian.

The wounds were examined visually, photographed, and X-rayed. Two specimens, each including wound tract, wound edge, and skin surface, were excised and fixed in buffered formalin and glutaraldehyde for routine histologic examination and scanning electron microscopy, respectively. The skin around the wounds was swabbed with cotton pledgets moistened with 5% nitric acid for subsequent analysis by flameless atomic absorptiometry; separate samples were obtained in each case from the circular area surrounding the defect (out to a 25-mm [1-in.] radius) and from the circumjacent areas from 25 to 51 mm (1 to 2 in.) and 51 to 76 mm (2 to 3 in.) from the wound. Finally, the remaining wound tract was excised to an average depth of 25 to 51 mm (1 to 2 in.) and submitted for carbon monoxide analysis.

From the formalin-fixed specimens, sections were cut and stained with hematoxylin and eosin and examined by light microscopy. The specimens fixed in glutaraldehyde were coated with gold and examined with a scanning electron microscope (Advanced Metals Research Model 1000). Each specimen was further subjected to energy-dispersive analysis of X-rays (EDAX Model 711B); each analysis included examination of the wound tract, the wound edge, and the adjacent skin surface. This analysis was strictly qualitative in nature.

The residual blood was expressed from the muscle of the excised wound tracts and analyzed for its carbon monoxide saturation with a Packard Model 417 gas chromatograph.

Swabs taken from around the wounds were submitted to the Forensic Science Branch of the U.S. Treasury Bureau of Alcohol, Tobacco and Firearms, where they were analyzed for barium and antimony with flameless atomic absorptiometer (Jarrell-Ash Model 810).

Silencer Construction

The noise of a firearm is the cumulative result of five distinct events. In chronologic order during firing these are (a) the fall of the hammer or firing pin, (b) the primer "pop" explosion and the associated shock waves, (c) the precursor wave, (d) the firing of the bullet, and (e) the propellant wave. Traditionally, few attempts have been made to reduce the noise of the hammer or firing pin or that produced by the primer pop, and since the silenced weapon must still fire a bullet, inevitably preceded by a precursor wave, most efforts have been directed towards controlling the noise of the propellant wave.

The quantity of sound produced by the propellant gas will vary directly with its velocity and its rate of expansion. The objectives of any silencer designed to suppress this source of noise should therefore be (a) to reduce the velocity of the gas before it leaves the weapon, (b) to control its expansion, and (c) to cool it, thereby reducing its volume and pressure and hence its escape velocity. Practical limitations, however, are placed on silencer construction by considerations such as the need for uninterrupted passage from the chamber to the end of the silencer to permit the bullet to leave the weapon and the acceptable weight and volume of the device. The objectives are generally met more or less efficiently by various combinations of three basic designs:

(1) an expansion chamber of a caliber greater than that of the weapon (ideally this should have a gas-tight junction with the weapon),

(2) the interposition of one or more centrally perforated baffles at right angles to the direction of gas flow (these divert the gas laterally, and the increased surface area assists in cooling the gas), and

(3) the insertion of some (usually) fibrous packing material into the expansion chamber (this partially absorbs the gas, and the enormous increase in surface area greatly facilitates its cooling).

Before the types of construction are considered in detail, two further general points need to be made.

First, if the expansion chamber is to achieve adequate volume with practical length, its diameter will almost invariably be such that the sighting system of the weapon will be obscured. This was true of all ten homemade silencers and of three of the six commercially manufactured silencers used in this series. Second, when the diameter of the perforation in the terminal baffle approaches that of the weapon caliber, alignment with the barrel becomes critical. For four of the homemade devices evidence of misalignment was obvious on inspection of the distal baffles.

The significance of these two points, alone or together, is that most silencers are suitable for use at close range only. Formal accuracy testing was not undertaken, but one obviously misaligned weapon deposited its missiles 102 mm (4 in.) from the point of aim at a range of 660 mm (26 in.)! For this reason, the authors believe that most intentional wounds inflicted by silenced weapons will have been produced at contact or close range.

Based on the extent of the modification of the weapon to which a silencer is fitted, it was possible to divide the silencer/firearm combinations into four groups. As will be noted later, these groups correspond well with noise-reduction efficiency.

Group I

Silencers for this group are designed to be attached to any unmodified weapon. In the typical example shown (Fig. 1), a collar, suitably recessed to accept the weapon's front sight, overlaps the barrel and is retained by a thumbscrew; the gas seal at this junction is invariably poor, and in the case of the recoil-operated weapon shown it is impossible to secure the silencer adequately to the barrel; therefore, it falls off each time the weapon is fired. This very inefficient silencer consisted of two concentric ported steel pipes, the interior one having a diameter of 17 mm. Between them was a packing of steel wool that had become concentrated at the distal end of the device, probably from repeatedly being dropped in use. The other example in this group consisted of a well-constructed expansion chamber with a hole only a little bigger than the caliber of the weapon in the distal baffle; because of the small exit hole and the imprecise fit to the barrel, it suffered badly from misalignment but was much more efficient as a sound suppressor.

One point is worth noting about the weapons used with Group I silencers: repeated tightening of the thumbscrews had produced small circular indentations some 2 to 3 mm in diameter about 15 mm from the ends of the barrels. Such marks on weapons may indicate past or present use with a Group I silencer.

Group II

With Group II silencers, the weapons had been modified slightly but no great metal-working skill or equipment was required for the modifications. Front sights were invariably lost. The crudest example tested consisted of a small engine muffler (Fig. 2) attached to some plumbing fixtures; the front sight of a .22-caliber Colt Woodsman had been removed and the end of the barrel was then driven hard into the plumbing fixtures, being retained

FIG. 1—*Group I silencer. The silencer is held in position by the thumbscrew. (AFIP Negative 78-4649-1.)*

FIG. 2—*Group II silencer. The front sight has been removed from the weapon, and the silencer is held in place simply by friction fit. (AFIP Negative 78-4649-2.)*

by friction fit. The interior of the silencer consisted of a ported pipe 19 mm in diameter with one crude baffle with a perforation 17 mm in diameter halfway along its length. The space between this inner pipe and the muffler was packed with steel wool.

A common refinement in this group was the threading of the outer surface of the barrel, permitting a more precise and gas-tight screw fit for the silencer. This was the commonest method of attachment for commercially manufactured silencers. Occasionally the *interior* of the barrel may be widened near its end and threaded to receive a silencer: weapons modified in this way may look entirely normal on cursory inspection.

Figure 3 shows a typical commercially manufactured silencer, designed to be fitted to an externally threaded .22-caliber weapon by means of the projection at the right-hand end of the device. The right half consists of a simple expansion chamber, while the left half contains nine perforated metal baffles (some of them are shown loose below the device) held in place by a threaded terminal baffle. The precision and rigidity of the screw fit permit much smaller baffle perforations without problems of misalignment.

Group III

Weapons in Group III were characterized by the most extensive modification. Although they could be fired without their silencers, the extent of the modification was such that the manufacturer obviously intended the silencers to be a permanent attachment. The devices in this group showed a high degree of personal skill on the part of their manufacturers and access to relatively sophisticated tools. It is interesting that only one commercially manufactured device was present in the six Group III silencers tested; although the other five were classed as homemade, that designation indicated "handmade" rather than crude or unsophisticated.

Figure 4 illustrates a typical example of a Group III device. The barrel has been exposed, threaded at its base, and drilled to form ports—in this case four sets of four at right angles. The aluminum expansion chamber, threaded at its proximal end, fits over the barrel and screws down firmly. It is packed with steel wool. The only baffle is the terminal baffle, and its perforation is similar in size to the caliber of the weapon; this particular device showed evidence of a mild degree of misalignment.

An interesting and very efficient variant of this type is shown in Fig. 5. The barrel contains very many small ports—about 120—and is threaded at its *distal* end. The ex-

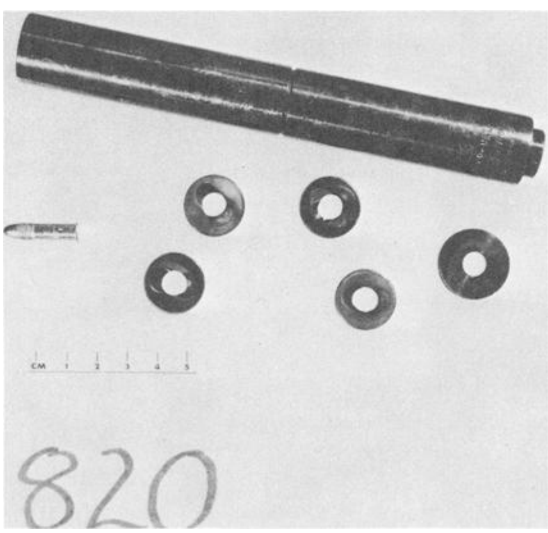

FIG. 3—*Group II silencer. This commercially manufactured device has a threaded collar (at the right end) and screws precisely over the threaded muzzle. The right half is an expansion chamber; baffles from the left half are seen loose with their retaining terminal baffle below the device. (AFIP Negative 78-4649-3.)*

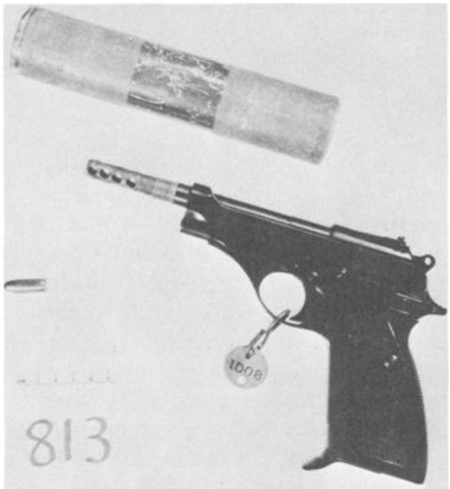

FIG. 4—*Group III silencers. The aluminum expansion chamber is packed with steel wool and screws over the base of the ported barrel. (AFIP Negative 78-4649-4.)*

FIG. 5—*Group III silencer. The expansion chamber screws over the* distal *end of the barrel so that the bullet remains in the barrel throughout its course through the weapon. (AFIP Negative 78-4649-5.)*

pansion chamber is a steel tube, open at its proximal end to fit snugly over the base of the barrel. The distal baffle is threaded to accept the distal end of the barrel. The packing material consists of several layers of copper gauze soldered rigidly together; the resulting copper gauze cylinder fits snugly around the barrel and totally fills the expansion chamber. This design shows two distinct advantages over the others: (1) the copper gauze permits more efficient cooling of the gases, thus enhancing the noise-reducing efficiency of the device, and (2) since the bullet remains in the barrel throughout its course through the weapon and silencer, no misalignment is possible. This particular device had the greatest noise reduction seen in this series.

Group IV

Group IV consists of weapons designed exclusively as silenced weapons. These have usually been manufactured for special military operations and, it is hoped, their use has been strictly controlled. However, the fact that the 0.32-caliber "Welrod" pistol (Fig. 6) representing Group IV devices in this series had been acquired by seizure is evidence of the periodic breakdown of such controls. The magazine—suitably covered for comfort—acts as the grip. A "grip safety" projects posteriorly, and the apparently crude trigger projects anteriorly; the weapon uses a modified bolt action. Very effective noise suppression is achieved by the large expansion chamber, the proximal half of which contains a highly ported barrel while the distal half contains a series of rubber baffles. The precision of manufacture is attested to by the fact that the perforation of the terminal steel baffle measures only 1.65 mm (0.065 in.) more in diameter than the measured caliber of the barrel; there was no misalignment.

Results

The study was divided into three groups of tests. These examined the effects of the silencers on certain aspects of the weapons' performance, the physical characteristics of the wounds, and, finally, certain chemical characteristics of them.

Weapon Performance

Sound Reduction—Table 1 lists the silencers tested in increasing order of noise reduction, shown as the difference in decibels between the recorded level for each weapon with and without its silencer. These readings represent peak impulse noise, and it should be remembered that the scale used is logarithmic; thus a change of −5 dB represents a noise reduction of about 65%, −10 dB represents 90% noise reduction, and −20 dB represents 99% noise reduction.

The weapons fall naturally, as it were, into their groups as described earlier, with no overlap among those tested. The sample is thought to be too small to make categorical

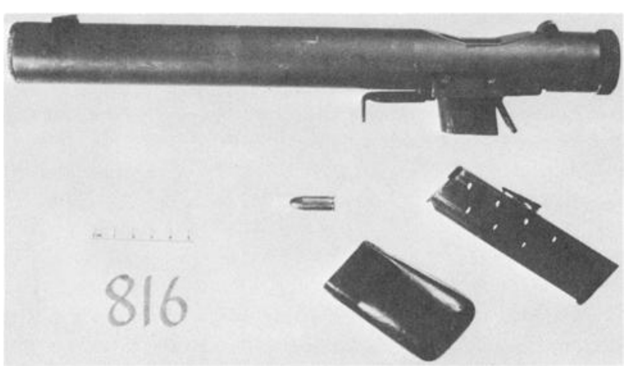

FIG. 6—*Group IV silencer. The silencing device is an integral part of the weapon; this particular design incorporates barrel ports, expansion chamber, and baffles. (AFIP Negative 78-4649-6.)*

TABLE 1—*Noise-reducing efficiency of weapons tested.*

Weapon	Manu-facture[a]	Group	Noise Reduction, dB
808	H	I	−0.8
804	H	I	−5.3
Group I average	...	...	−3.1
814[b]	H	II	−5.4
807	H	II	−7.6
824	H	II	−11.4
811	C	II	−16.0
819	C	II	−16.9
818	C	II	−17.9
820	C	II	−22.0
Group II average	...	...	−13.9
809	H	III	−23.9
823	C	III	−24.6
813	H	III	−25.5
810	H	III	−25.8
815	H	III	−27.7
806	H	III	−28.1
Group III average	...	...	−25.9
816[c]	C	IV	−32.4

[a]H = homemade and C = commercially made.
[b]Silencer not removable. Figure for noise reduction based on comparison with unsilenced control of same caliber.
[c]Silencer integral part of weapon. Figure for noise reduction based on comparison with unsilenced control of same caliber.

statements based on this observation, but there appears to be a strong correlation between design and efficiency in terms of noise suppression. These group differences are exaggerated for illustrative purposes by showing the arithmetic average for each group.

With the exception of the one commercially manufactured weapon in Group IV, commercially manufactured silencers were inferior to all but one of the handmade models in Group III. This finding appears to underline the difficulty in controlling the distribution of efficient silencing devices for firearms and to emphasize the importance of detecting their use.

We attempted to correlate noise reduction with the caliber of the weapon to find out if weapons of some calibers were easier to silence than others. The number of weapons in the study did not permit a formal statistical analysis, but the impression gained was that .32-in. and 9-mm weapons were harder to silence than .45-in. and .22-in. weapons. This finding was in keeping with the experience of one of the authors (R. J. S.), who deals regularly with the measurement of silencer efficiency.

Finally, a regular foam-filled domestic pillow was folded around a Colt .38 Special revolver. The resultant noise reduction was 15.4 dB (>95%) and was better than five more-or-less elaborately constructed metal devices.

Missile Velocity—There were so few examples of Groups I and IV that it is not possible to comment on the effects of these types of silencers on missile velocity.

Table 2 gives the results of test-firing each weapon with and without its silencer; the figures quoted show the range of change in missile velocity after subtraction of the "velocity unsilenced" from the "velocity silenced." As will be seen, the overall effect of Group II devices was to produce a small increase in missile velocity, while that of Group III devices was to reduce missile velocity. These trends are maintained even when the highest and lowest changes in each group are discarded in the final average and so are thought to be valid.

The reasons for these changes are fairly simple to understand. A well-fit Group II silencer represents, in effect, an extension of the weapon's barrel and permits the propellant gas to act on the missile for a longer period, albeit at reduced pressure. In contrast, the modifications to the barrel seen in Group III devices permit an early reduction in the gas pressure in the chamber and barrel, corresponding in effect to a reduction in the time the missile is in the barrel. It is, however, stressed that these comments are broad generalizations, and many factors—the quality of workmanship and validity of design being not the least of these—will influence the effect of a silencer on missile velocity.

It is stressed that in our experience these changes in missile velocity and hence bullet kinetic energy are small and, especially over the ranges within which silencers are likely to be used, insignificant as well as unpredictable. Even in the case of the greatest reduction in velocity seen (38.7 m/s [128.9 ft/s]), the kinetic energy of the bullet was still 224.0 J (165.9 ft · lbf)—more than enough to be lethal by any standards. We think, therefore, that any argument, for example in court, that the attachment of a silencer could be taken to indicate intent either to increase or to decrease the lethal potential of a firearm based on the type of measurements reported here should be strongly resisted.

Bullet Appearance—While none of the authors is competent in the fields of toolmark examination or comparison microscopy, it seemed likely to us that the effects of silencer misalignment and barrel modification might produce gross changes that might on occasion be easily recognized. Although we do not advocate anything short of a complete laboratory workup of every firearms case, such an investigation takes time, and a well-founded suspicion voiced by the law enforcement agent or pathologist who first recovers the bullet may be of the greatest investigative value.

Figure 7 illustrates bullets recovered in the course of the study. Bullets *a, b,* and *c* are from control weapons of 0.22-, 0.32-, and 0.45-caliber weapons, respectively; *b* and *c* are copper-jacketed. The marks representing the barrel rifling are clearly visible. Bullets *d* and *e* are for comparison with *a; e* was fired from a poorly aligned Group I silencer and shows very pronounced, rather spiral shaving along one edge. Bullet *d* was fired from a Group III silencer with an extensively ported barrel. Such porting is achieved by drilling through the barrel, and the drilling leads to irregular tongues of steel projecting into the barrel. None of the barrels examined had been rebroached after being drilled. These tongues are abrasive and lead to effacement of the marks caused by the lands and grooves and to their replacement by coarse longitudinal spiral lines. Bullet *f* is the same caliber as bullet *b* and is from a Group III device that was both ported and misaligned; the copper jacket shows a deformity comparable to the shaving of Bullet *e* in addition to some degree of effacement of rifling marks. Finally, Bullet *g* is from a Group III silencer of the same caliber as *c*; there was no detectable misalignment, but the marked effacement of the lands and grooves is easily recognized.

These deformities were so extensive that they could be reliably detected on examination of the bullets by the naked eye or with a ×10 hand lens in about one third of the bullets examined in this series and were limited to silencers of Groups II and III.

TABLE 2—*Effect of firearm silencers on missile velocity.*[a]

Group	Range of Change, ft/s	Group Average, ft/s
II	−3.5 to +26.1	+12.6
III	−128.9 to +19.4	−20.4

[a] 1 ft/s = 0.30 m/s.

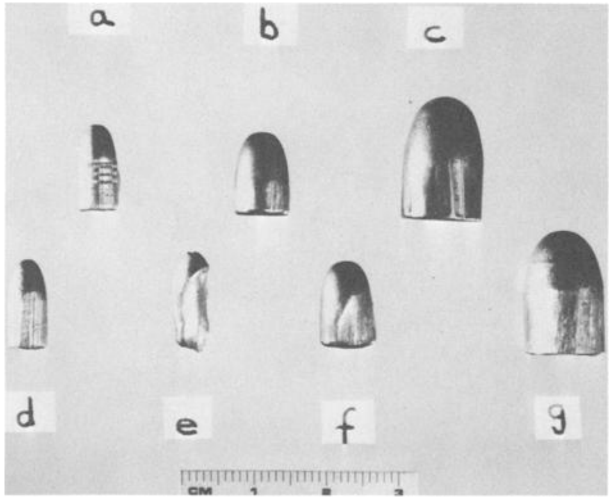

FIG. 7—*Examples of bullets fired from control weapons (*a, b, *and* c*) and silenced weapons (*d, e, f, *and* g*). See text for explanation. (AFIP Negative 78-4649-7.)*

Physical Characteristics of Wounds

Contact Wounds—Despite firm muzzle-to-skin pressure, we were unable to produce the typically lacerated "hard" contact wound with any of the silenced weapons tested, presumably in part because of the escape of propellant gases at the points of silencer attachment and in part because of the permitted expansion of these gases within the devices.

Most of the "loose" contact wounds produced differed little from those inflicted by the control weapons and showed the typical circumscribed defect, circumferential abrasion, and fouling around the abrasion; soot was also present in the wound tract. Significant differences were found in both the character and the size of the muzzle imprints.

First, instead of the usual abrasion, the imprints from the silenced weapons were erythematous circles having sharply defined edges (Fig. 8). These were sometimes complete and sometimes partial circles, the latter configuration indicating the area of most pressure between weapon and target. The contrasting character of these muzzle imprints is well seen histologically in Fig. 9, where the relative absence of thermal or mechanical damage in the lower wound from a silenced weapon is conspicuous. At higher magnification (Fig. 10), dilation of the capillaries in the upper dermis is demonstrated within the area of the imprint; this effect was not seen in wounds inflicted with unmodified weapons.

In addition to the unusual character of these imprints, their size is also considered to be a valuable feature; thus, a muzzle imprint some 40 mm in diameter associated with a defect and an abrasion collar 5 mm in total diameter should suggest, at the very least, an unusual or modified weapon. Measurement of the total diameter of the imprint, or where the circle is incomplete its estimation, is important; in this study we were able to predict the diameter of the terminal end of the silencers to an accuracy of ± 2 mm. Furthermore, in two cases where the silencers were mounted eccentrically, this eccentricity could be clearly detected by comparing the imprint with the entry wound, and the dimensions and configuration could be established by appropriate measurement.

Noncontact Wounds—On account of the lack of consistent discriminatory findings,

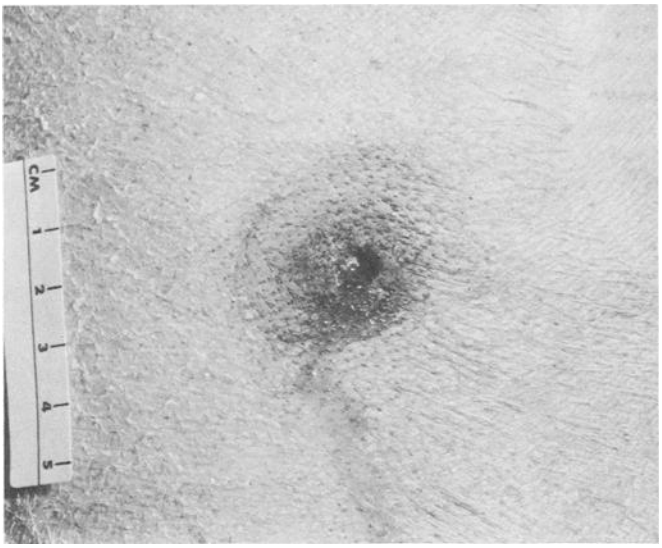

FIG. 8—*Contact wound from silenced weapon. In this instance, most of the pressure was applied to the left of the entrance hole, and the muzzle imprint is sharpest there. Note disproportion between apparent caliber of weapon and diameter of muzzle. (AFIP Negative 78-4649-8.)*

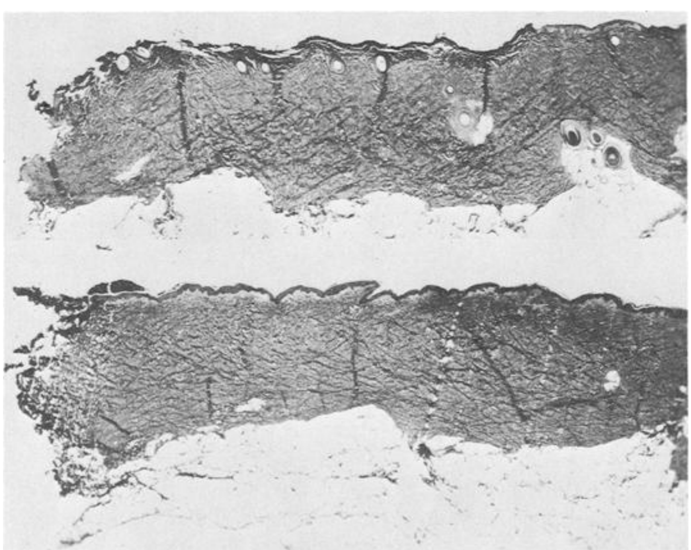

FIG. 9—*Low-power photomicrograph of contact wounds inflicted by control weapon* (above) *and silenced weapon* (below). *The marked mechanical and thermal damage associated with the muzzle of the control weapon is absent in the case of the silenced weapon. (Hematoxylin and eosin stain.) (AFIP Negative 78-4649-9.)*

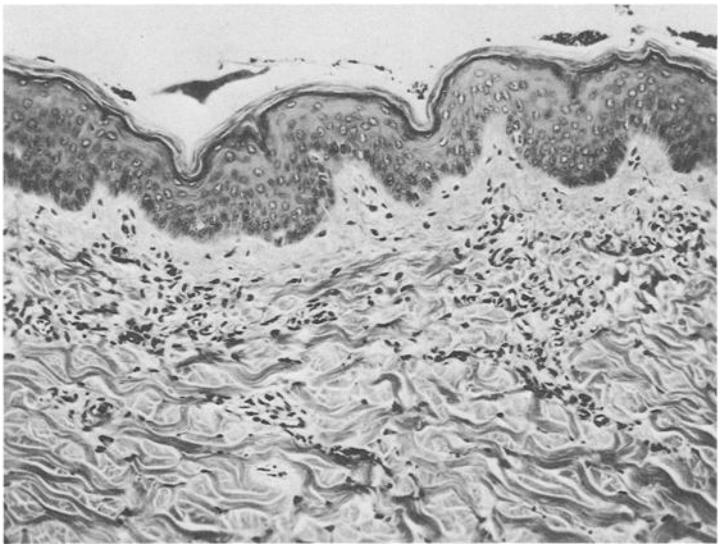

FIG. 10—*Skin from within area of muzzle imprint from silenced weapon. Powder residue is seen on the surface, and there is an absence of marked mechanical or thermal changes. Note moderate dilation and congestion of upper dermal capillaries. (Hematoxylin and eosin stain.) (AFIP Negative 78-4649-10.)*

the wounds inflicted at 305 and 660 mm (12 and 26 in.) have been grouped together simply as "noncontact."

In unmodified weapons, of course, it would be expected that the quantity and dispersion of stippling or tattooing by powder on the skin surface would help to differentiate wounds at these ranges from one another. Indeed, the range of 660 mm (26 in.) was chosen as the best compromise point at which such stippling disappeared with the control weapons and ammunition, rendering wounds produced at this range "distant" from a pathologic viewpoint. Table 3 lists the findings with regard to stippling, caliber, group, and increasing efficiency within each group. The overall tendency for the silencers to reduce both the density and the radius of the stippling around the wound is more marked in Group III than in Group II. This finding, however, is rather of academic interest: it is inconsistent and the finding of a *reduction* of a substance in a situation where no control is available (such as a homicide) is impossible.

The most significant and helpful observation in the group of noncontact wounds was the occurrence of atypical entrance wounds, characterized by irregular or slit-like defects, often with eccentric abrasion collars and some laceration around the defect (Fig. 11). Atypical entrance wounds with these and other features may be found in other situations when bullets are in unstable, nonaxial flight. The commonest cause of this in practice is an intermediate target causing a ricochet, such as another part of the body, jewelry, objects in pockets, furniture, architectural structures, or the ground. Unstable flight also occurs when a bullet is deformed during firing because of an inappropriate weapon/ammunition combination or poor weapon construction. Finally, atypical entrance wounds may result from secondary missiles generated by the bullet, which itself may or may not also strike the body. The authors think that the silencer, particularly if it is misaligned, should be added to this list. Except for the use of inappropriate ammunition for a given

TABLE 3—*Effects of silencers on powder stippling around noncontact wounds.*

Weapon	Caliber	Group	305-mm (12-in.) Range Density[a]	305-mm (12-in.) Range Radius[b]	660-mm (26-in.) Range Density[a]	660-mm (26-in.) Range Radius[b]
805	0.22 in.	control	m	35	0	...
804	0.22 in.	I	0	...	0	...
807	0.22 in.	II	m	30	0	...
819	0.22 in.	II	m	20	0	...
818	0.22 in.	II	s	12	0	...
820	0.22 in.	II	s	24	0	...
809	0.22 in.	III	0	...	0	...
810	0.22 in.	III	s	32	0	...
815	0.22 in.	III	0	...	0	...
806	0.22 in.	III	0	...	0	...
812	0.32 in.	control	m	48	0	...
824	0.32 in.	II	0	...	0	...
813	0.32 in.	III	0	...	0	...
816	0.32 in.	IV	0	...	0	...
802	9 mm	control	m	32	s	31
808	9 mm	I	s	25	0	...
814	9 mm	II	0	...	0	...
801	0.45 in.	control	m	45	0	...
811	0.45 in.	II	0	...	0	...
823	0.45 in.	III	0	...	0	...

[a]Visual assessment of density of stippling: m = moderate, s = scanty, and 0 = absent.
[b]Distance in millimetres from the wound edge to the outermost margin of stippling.

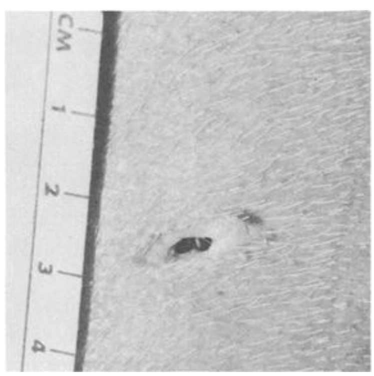

FIG. 11—*A typical slit-like entry wound resulting from misaligned silencer. (AFIP Negative 78-4649-11.)*

weapon or poor weapon construction, the other causes of atypical entrance wounds can usually be excluded by a careful examination of the body and the scene.

Radiological Observations—Since it is generally accepted that radiographs of the body should always precede an autopsy (or surgical procedure) in cases of injury resulting from firearms, each wound was X-rayed. Not surprisingly, the findings were not specific for gunshot wounds, and there were no detectable differences between wounds inflicted by unmodified and silenced firearms. Most of the wounds perforated the animals, but a few exhibited penetration only. As bullets deform unpredictably after entering a body and as shapes of metallic foreign bodies are difficult to interpret on X-rays, even when seen in several planes, it is *not* recommended that shapes resembling the deformed bullets illustrated in Fig. 7 (*e* and *f*) serve as evidence that the bullets have been fired from a silenced weapon.

Light Microscopic Observations—Except for the differences already described for contact wounds, histologic examination of the wound edges failed to discern any recognizable features that would distinguish wounds caused by silenced weapons from those caused by unmodified weapons. Only entrance wounds were studied, and these showed the usual characteristics of progressive epithelial thermal and mechanical changes as the defect is approached, thermal changes in the dermal collagen, and varying amounts of powder residue in the wound tract and on the epithelial surface.

The amount and distribution of the powder residue varied enormously even at the same ranges with the control weapons of different calibers. Although in general the contact wound tracts contained more powder than those of the noncontact wounds, the variation in amount and the overlap with the amount of residue seen in close-range wounds made estimation of range by histological appearance of the wounds quite unreliable, even in the control series.

This finding raises a question concerning the validity of estimating range of fire from histologic material at all. It is thought that, at present, examination of wounds by naked eye, hand lens, and dissecting microscope offers a much more reliable technique for assessing the likely range at which a weapon was fired.

Observations by Scanning Electron Microscopy—The typical SEM appearances of gunshot entrance wounds are seen in Figs. 12 and 13. Figure 12 represents a contact wound inflicted by a silenced weapon from Group III. The skin surface shows an area of abrasion immediately adjacent to the defect. Some "shelving" is seen in the upper part of the tract; this was quite common and was correlated with separation of the epidermis and subepidermal collagen from the deeper dermal collagen, most probably as a result of gas dissecting the tissues. The surface of the wound tract is composed of collagen, denatured by heat from the missile (and gases in contact wounds), and has a granular appearance with pits of various sizes opening onto it (Fig. 13). These pits are shaped like hollow spheres and are considered to be the result of vaporization and consequent expansion of tissue fluid. Powder residue, when present, appeared as light, amorphous, fluffy foreign material both on the skin surface and within the tract.

With one exception to be described below, variations between the appearances related only to the extent of surface abrasion and the presence or absence of "shelving" and powder residue. All of these features could be demonstrated more clearly, more quickly, and more cheaply by other means. In general, there were no specific appearances permitting differentiation between wounds caused by unmodified and silenced weapons. Furthermore, when bleeding had been marked, the appearances described were often totally obscured by fibrin and red blood cells.

The one exception where examination by SEM revealed evidence for suspicion of the use of a modified weapon was with the contact and 305-mm (12-in.) range wounds produced by the weapon shown in Fig. 5; a bullet fired from this weapon is depicted in Fig. 7d. The finding consisted of large amounts of light material appearing as plaques of sharp spicules apparently fused at their bases (Fig. 14), shown by EDAX to be lead. This appearance could be reproduced by dropping molten lead onto a microscope slide at room temperature. We think that the cause of this phenomenon is increased friction between, in this case, a lead bullet and the barrel of the weapon, because of the modifications already described in the latter. The heat produced by this friction causes fusion of the outer surface of the bullet, and when the bullet emerges from the muzzle, it is accompanied by a shower of molten lead, some of which solidifies on impact with the target.

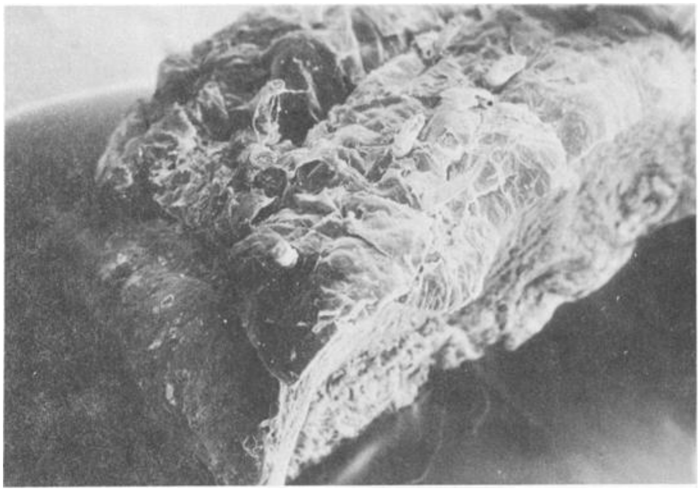

FIG. 12—*Scanning electron photomicrograph of contact gunshot wound caused by silenced weapon. The wound is to the left of the specimen. Abrasion is limited to the wound edge, and there is some gas dissection ("shelving") between the epidermis and the dermis. (AFIP Negative 78-4649-12.)*

FIG. 13—*Scanning electron photomicrograph of gunshot wound tract showing the granular denatured dermal collagen and the smoother partially spherical pits. The white "fluffy" material is powder residue. (AFIP Negative 78-4649-13.)*

It is stressed, however, that the *quantity* of this material in and around the wound is important; an occasional lead plaque could be found in other wounds inflicted by weapons firing plain lead bullets, presumably the result of a heat-induced fusion or of "leading" of the barrel, since no modifications or structural defects could be demonstrated. In these latter cases, however, such plaques were hard to find; in the wounds described, the plaques were hard to miss.

FIG. 14—*Part of a plaque of lead found around one of the wounds caused by the weapon seen in Fig. 5 (the gun has an extensively ported barrel). See text for explanation. (AFIP Negative 78-4649-14.)*

Chemical and Physiochemical Examinations

Carbon Monoxide in Wound Tracts—Table 4 shows the results of the investigation of carbon monoxide in the wound tracts. Control samples of venous blood from the animals had levels of up to 1% saturation; any finding in a wound of 1% saturation or below was therefore treated as negative. The table also shows the difficulty experienced in obtaining, either by mechanical or chemical means, sufficient hemoglobin on which to perform the estimations. This was anticipated during the biopsies because none of the muscle appeared cherry red and, indeed, all of the muscle was notably pale, probably at least partly because of the use of general anesthesia with its attendant hypotension. As a result of the great variation in the quantity of assayable hemoglobin, the results are reported simply as "present" or "absent" rather than as a percentage of saturation of hemoglobin with carbon monoxide. The lowest actual value recorded as present was 2.8% saturation—almost three times the level found in the animals' blood.

Two points are worth making from these results. First, carbon monoxide was detected at a range of 305 mm (12 in.) from the target with the 9-mm and 0.45-in.-caliber control weapons; it is not known whether or not it was present at the same range with the other two controls. Both of these weapons were handguns, and the percentage of saturation was relatively high in both cases (15.7 and 11.6% for the 9 mm and the 0.45 in., respectively). Therefore, detectable levels of carbon monoxide may be found in wounds inflicted by handguns of these calibers at least up to ranges of 305 mm (12 in.).

Second, detectable carbon monoxide was absent in two contact wounds, each inflicted by a different, silenced weapon. The contact wound caused by Weapon 816 (Fig. 6) had the features of a classic loose contact wound except that the muzzle imprint was disproportionately large. In the wound inflicted by Weapon 823, there was no surface fouling, but powder residue in the tract was plentiful, and, again, a muzzle imprint of a diameter disproportionately large for the estimated caliber was present. The *absence* of detectable

TABLE 4—*Gas chromatographic analysis of blood from around the wound tracts for carbon monoxide.*

			Carbon Monoxide[a]		
Weapon	Caliber	Group	Contact	305-mm (12-in.) Range	660-mm (26-in.) Range
805	0.22 in.	control	+	—[b]	—
804	0.22 in.	I	+	0	—
807	0.22 in.	II	+	0	0
819	0.22 in.	II	+	0	—
818	0.22 in.	II	+	0	—
820	0.22 in.	II	+	0	0
809	0.22 in.	III	+	0	0
810	0.22 in.	III	+	0	0
815	0.22 in.	III	+	0	0
806	0.22 in.	III	+	0	—
812	0.32 in.	control	+	—	0
824	0.32 in.	II	+	—	—
813	0.32 in.	III	—	—	0
816	0.32 in.	IV	0	0	0
802	9 mm	control	+	+	—
808	9 mm	I	—	0	0
814	9 mm	II	+	—	0
801	0.45 in.	control	+	+	0
811	0.45 in.	II	+	0	0
823	0.45 in.	III	0	0	—

[a] + = percentage of carbon monoxide saturation greater than 2.8 and 0 = less than 1.0%.
[b] — = insufficient blood expressed or eluted to permit analysis.

carbon monoxide in obvious contact wounds should apparently be considered to be consistent with the use of a silenced weapon.

Energy Dispersive Analysis of X-rays—The EDAX was conducted on the biopsy specimens taken for SEM examination. We did this test because we believed it would demonstrate elements not usually found in and around wounds produced by semiautomatic weapons; the presence of such elements could then be related either to modifications to the weapon or to the components of the silencer or both. Table 5 gives the results for the elements detected in the wounds produced by control weapons. Weapons 805, 802, and 801 are completely unmodified; Weapon 812, however, had had its barrel externally threaded to receive a screw-fit Group II silencer. To our surprise, this apparently minor modification and the friction of attaching and removing the silencer had apparently led to the release of particles containing iron, nickel, and manganese, probably from the steel from which the barrel was cast. The elements found consistently among the control group were regarded as "normals" and, with the exception of the iron, nickel, and manganese explained above, are not included in Table 6, which shows only the "unusual" elements detected in and around the wounds caused by silenced weapons; normal elements were consistently found, of course, associated with these wounds. The results are all purely qualitative.

As an overall control, skin from areas well away from the wounds was subjected to EDAX, and none of the normal or unusual elements were detected.

Flameless Atomic Absorptiometry—Tables 7 and 8 record the recovery by flameless atomic absorptiometry of barium and antimony, respectively, from around the wounds. The results are grouped by caliber and range. The test results are arithmetic averages for the given caliber at the stated range and within the defined areas.

There is very little evidence of the expected progressive fall-off of recovery with increasing

TABLE 5—*Results of EDAX from wounds produced by control weapons.*

Weapon	Caliber	Elements Detected: Contact	Elements Detected: 305-mm (12-in. Range)	Elements Detected: 660-mm (26-in.) Range
805	0.22 in.	lead, zinc, copper	lead	lead
812	0.32 in.	lead, zinc, copper, barium (iron, nickel, manganese)[a]	lead, zinc, copper, barium (iron, nickel)[a]	lead, copper (iron)[a]
802	9 mm	lead, zinc, copper, barium	lead, zinc, copper, barium, antimony	lead, copper
801	0.45 in.	lead, zinc, copper	lead, zinc, copper	lead, zinc, copper, barium

[a] See text for explanation.

distance from the wound. This is true for the unmodified weapons as well as for those fitted with silencers and is most marked with the smallest caliber. What regular progressive fall-off in recovery is found is more consistent with barium than with antimony, being seen with 14 sets of results (8 controls and 6 tests) for the former as compared with 10 sets of results (5 controls and 5 tests) for the latter. However, the degree of numerical overlap is such that it is, in effect, impossible to predict caliber or range in a given instance from the amount of either barium or antimony recovered. Consideration of total elemental recovery within a 76-mm (3-in.) radius did not reduce this overlap, and rearrangement of the results by silencer group rather than by caliber abolished what little correlation there was.

In several instances the recovery of barium and antimony from comparable areas of wounds inflicted by silenced weapons *exceeded* that from wounds produced by control weapons, particularly for barium. The reason for this is not readily discernible, although turbulence of the propellant gases and therefore increased deposition of elements carried by them onto the skin surface may be suggested. Again, unfortunately, overlap of the amounts recovered precluded supporting or refuting a finding that a wound resulted from a silenced weapon.

There was a considerable difference between this technique and EDAX in the recovery of these elements. With flameless atomic absorptiometry, out of the 60 wounds examined, barium was not detected around one, antimony was not detected around nine, and neither was detected around only one; with EDAX, barium *was* detected around 20 wounds, antimony around one, and both elements together around one.

Discussion

There were basically two objectives of this study: to present information on the structure and function of firearm silencers and to establish any characteristics that may indicate to the pathologist that a given wound may have been inflicted by a silenced weapon.

Based on observations of silencer construction, it is again stressed that most intentional wounds are, in our opinion, likely to be produced at contact or close range. Since we were unable to produce typical hard contact wounds with any of the silenced weapons, we think such a wound is unlikely to be the product of a silenced firearm, but, broadly speaking, such a weapon should be included in the pathologist's differential diagnosis of all loose contact wounds, especially in view of the increasing number of seizures of silenced weapons.

In the case of such a contact wound, examination of the muzzle imprint—both macroscopically and microscopically—with appropriate measurements is probably the best

TABLE 6—*Unusual elements detected by EDAX from wounds produced by silenced weapons.*

				Elements Detected		
Weapon	Caliber	Group	Silencer Construction	Contact	305-mm (12-in.) Range	660 mm (26-in.) Range
804	0.22 in.	I	steel tube	iron	nickel, manganese	iron, nickel
807	0.22 in.	II	steel muffler with steel wool	iron, nickel, chromium, silicon	. . .	silicon
819	0.22 in.	II	steel	iron, chromium	. . .	iron
818	0.22 in.	II	steel	iron, silicon	nickel, chromium	iron, nickel
820	0.22 in.	II	steel	iron, chromium	. . .	iron, nickel
809	0.22 in.	III	steel with foam rubber	iron, silicon	silicon	. . .
810	0.22 in.	III	steel tube with copper gauze	iron, nickel, silicon	iron	nickel
815	0.22 in.	III	steel	iron, nickel	iron, nickel	iron, chromium
806	0.22 in.	III	steel tube with copper gauze	. . .	. . .	. . .
824	0.32 in.	II	steel	iron, nickel, silicon	iron, nickel	iron, nickel
813	0.32 in.	III	steel wool packing	iron	iron, nickel, manganese	iron, nickel, silicon
816	0.32 in.	IV	steel and rubber	iron, nickel, manganese, chromium, silicon	iron, nickel, chromium	iron, nickel
808	9 mm	I	steel and steel wool	iron, nickel	iron, nickel	iron, nickel
814	9 mm	II	steel	iron, nickel, silicon	iron, nickel, manganese, silicon	iron, nickel, silicon
811	0.45 in.	II	steel and rubber	iron, silicon	iron	iron
823	0.45 in.	III	steel and rubber	iron	iron	iron, nickel

TABLE 7—*Total recovery of barium by flameless atomic absorptiometry of swabs taken from around the wounds* (μg).

Caliber	Weapon	Range	Area 1[a]	Area 2[b]	Area 3[c]
0.22 in.	control	contact	0.03	0.04	0.04
0.22 in.	test	contact	0.20	0.28	0.08
0.22 in.	control	12 in.	<0.02	0.04	0.04
0.22 in.	test	12 in.	0.27	0.20	0.27
0.22 in.	control	26 in.	0.60	0.56	0.58
0.22 in.	test	26 in.	0.73	0.63	0.46
0.32 in.	control	contact	1.50	0.39	0.42
0.32 in.	test	contact	>2.0	>2.0	>1.96
0.32 in.	control	contact	>1.50	>1.50	1.11
0.32 in.	test	12 in.	>1.52	>1.74	>1.64
0.32 in.	control	26 in.	0.75	0.60	0.60
0.32 in.	test	26 in.	0.72	0.50	0.51
9 mm	control	contact	0.58	0.35	0.20
9 mm	test	contact	>1.50	1.31	0.72
9 mm	control	12 in.	>1.20	>1.20	>1.20
9 mm	test	12 in.	1.02	1.10	1.08
9 mm	control	26 in.	0.88	0.56	0.48
9 mm	test	26 in.	0.76	0.67	0.59
0.45 in.	control	contact	>1.20	0.77	0.45
0.45 in.	test	contact	>1.50	>1.35	>1.23
0.45 in.	control	12 in.	>1.20	1.10	0.84
0.45 in.	test	12 in.	>1.25	>1.50	1.14
0.45 in.	control	26 in.	0.75	0.60	0.43
0.45 in.	test	26 in.	0.97	1.11	1.39

[a] Area 1 = circle with 25-mm (1-in.) radius from center of wound.
[b] Area 2 = circular band 25 mm (1 in.) wide with inner radius 25 mm from center of wound.
[c] Area 3 = circular band 25 mm (1 in.) wide with inner radius 51 mm (2 in.) from center of wound.

indicator of silencer usage. The presence of an imprint disproportionately large for the size of the wound and consisting of a concentric or eccentric erythematous area having a sharply defined periphery should be regarded as good evidence that a silenced firearm was involved. As noted, measurement of the diameter of this area, at least in a recently dead body, may be expected to accurately reflect the size of the terminal baffle of the silencer and may therefore be of considerable investigative and evidential value.

Where the wound is not clearly a contact wound, the possibility that it was inflicted by a silenced firearm should be added to the list of causes of atypical entrance wounds and borne in mind by the pathologist. The amount of tattooing or stippling on the skin surface is of no value in detecting the use of a silencer. Light microscopy of biopsy specimens from the wound edge is likewise not helpful, except as already described for muzzle imprints and, based on studies of wounds inflicted at known ranges by the control weapons, appear to us to be of little value in the overall assessment of range of fire. This latter point deserves further study in view of other published material [7].

Scanning electron microscopy alone offered little help in differentiating wounds from silenced and unmodified weapons, except as noted in the case of the one extensively modified barrel that caused excessive lead to be present around the wound. The technique also suffers from its lack of universal availability and its cost. Energy dispersive analysis of X-rays, however, was thought to be potentially very helpful; the demonstration of "unusual" elements around the wounds must be taken as strong supportive evidence for the use of a silencer. The presence of aluminum was ignored, since it was used to hold the specimen in the chamber of the machine; the elements recorded in Table 6 represent those found in various types of steel and, in some cases, excessive silica from foam rubber.

TABLE 8—*Total recovery of antimony by flameless absorptiometry of swabs taken from around the wounds* (*μg*).

Caliber	Weapon	Range[a]	Area 1[b]	Area 2[b]	Area 3[b]
0.22 in.	control	contact	0.03	nil	nil
0.22 in.	test	contact	0.13	0.02	0.01
0.22 in.	control	12 in.	0.38	0.15	0.08
0.22 in.	test	12 in.	0.13	0.14	0.12
0.22 in.	control	26 in.	0.02	0.02	0.01
0.22 in.	test	26 in.	0.01	0.01	0.01
0.32 in.	control	contact	1.00	0.22	0.31
0.32 in.	test	contact	0.09	0.03	0.02
0.32 in.	control	12 in.	0.50	0.50	0.50
0.32 in.	test	12 in.	0.19	0.08	0.03
0.32 in.	control	26 in.	0.01	0.02	0.02
0.32 in.	test	26 in.	nil	nil	nil
9 mm	control	contact	0.80	0.18	0.09
9 mm	test	contact	0.30	0.03	0.03
9 mm	control	12 in.	1.00	0.46	0.34
9 mm	test	12 in.	0.03	0.03	0.04
9 mm	control	26 in.	nil	nil	nil
9 mm	test	26 in.	nil	nil	nil
0.45 in.	control	contact	1.00	0.12	0.10
0.45 in.	test	contact	0.49	0.20	0.19
0.45 in.	control	12 in.	0.54	0.38	0.16
0.45 in.	test	12 in.	0.50	0.30	0.27
0.45 in.	control	26 in.	0.01	0.03	0.01
0.45 in.	test	26 in.	nil	nil	nil

[a] 1 in. = 25.4 mm.
[b] The areas are the same as those described for Table 7.

These findings are of most value when it is known that a semiautomatic weapon was used, such as may be determined by the markings on a recovered bullet or the presence of cartridge cases at the scene. Care must be exercised, however, in the interpretation of this finding when the type of weapon is unknown; in a separate study [*8*], we demonstrated the presence of iron and nickel in wounds inflicted by revolvers. The findings by EDAX should therefore be judged in conjunction with other findings in any given case.

Examination of expressed or eluted blood from a wound tract for carboxyhemoglobin is admittedly unlikely to become an established routine in the investigation of gunshot wounds. In cases when the wound appearances are those of loose contact, however, and there are other grounds for suspecting the use of a silenced firearm, the *absence* of carboxyhemoglobin at levels above that of control blood from the victim may be taken as supportive. Conversely, it should be remembered that the presence of even fairly high levels of carboxyhemoglobin in a wound of dubious range does not necessarily support its being a contact wound.

Radiology, while maintaining its vital traditional role in the investigation of gunshot wounds, offers little assistance in supporting or refuting the use of a silenced weapon. Likewise, flameless atomic absorptiometry of swabs from around the wound appears to be valueless in making such a differentiation and indeed to have little place in the establishment of likely caliber or range. The demonstration of barium and antimony may, however, be useful when the *nature* of the wound itself is in doubt, as may be the case in dismembered or decomposed bodies; when undertaken for this purpose, EDAX is no substitute for FAA.

Examination of recovered missiles is not traditionally part of the task of the pathologist.

We suggest, however, that inspection by naked eye and hand lens should always be done before the material is referred to the firearms examiner. If the deformities illustrated in Fig. 7 can be recognized with any degree of certainty, the suggestion that the missile could have been fired from a silenced weapon is, in our opinion, merited; this may be of considerable investigative value to law enforcement agents.

Conclusions

Like so many other diagnoses in forensic pathology, the diagnosis of a wound's being produced by a silenced firearm cannot be made positively on the basis of any one simple piece of evidence. Rather it must be made—or excluded—by the painstaking assembly of many small pieces of evidence from different sources and techniques. The first stage in such a situation, of course, is an awareness that the problem exists and a knowledge of how to go about solving it.

Primarily with the forensic pathologist in mind, we have discussed what appears to be an increasing problem in the community and indicated ways in which the use of firearm silencers may be detected. Based on our results, we feel confident that such detection is not only possible but feasible in most instances.

Acknowledgments

The authors gratefully acknowledge the assistance of the following: Mr. William H. Richardson, acting assistant director (Technical and Scientific Services), Department of the Treasury, Bureau of Alcohol, Tobacco and Firearms, Washington, D.C., for permitting the participation of R. J. S. and the Forensic Science Branch of that Bureau in the project; the staff of the Photographic Division, Medical Illustration Service, Armed Forces Institute of Pathology, Washington, D.C., for preparation of all the illustrations; Major George W. Irving, III, DVM, USAF, VC, chief, Laboratory Animal Medicine, Armed Forces Institute of Pathology, Washington, D.C., and staff for care and management of the animals before, during, and after the project and for taking and developing the X-rays; Mrs. Francine R. Hincherick, chief of histopathology, Department of Geographic Pathology, Armed Forces Institute of Pathology, Washington, D.C., and staff for preparation of the histologic slides; Sgt. Linda M. Helsley, USAF, and SSgt. Walter E. Saddler, USAF, for considerable assistance with the scanning electron microscopy and EDAX; Dr. Leo R. Goldbaum and CMSgt. Alan E. Petty, USAF, Division of Toxicology, Armed Forces Institute of Pathology, Washington, D.C., for undertaking the gas chromatographic analyses for carboxyhemoglobin; Mr. Charles R. Midkiff, Forensic Science Branch, U.S. Treasury Bureau of Alcohol, Tobacco and Firearms, Washington, D.C., for undertaking the flameless atomic absorptiometry; and Captain Robert L. Thompson, MC, USN, chairman, Department of Forensic Sciences, Armed Forces Institute of Pathology, Washington, D.C., for editorial and publishing assistance after the departure from AFIP of two of the authors (R. C. M. and D. I. L.).

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