CASE REPORT

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A Shot Through the Window

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ABSTRACT: At issue in this case was whether an unusual window defect seen in two of the crime scene photographs was due to a bullet and if so, if that same bullet fatally wounded the victim. The window appeared to have been cracked prior to the apparent shot through it. A .22 bullet recovered from autopsy, when examined only by light microscopy, failed to show associated glass fragments.

A previously cracked test window was shot a number of times with .22 caliber bullets near the cracks in an effort to simulate the window defect seen in the crime scene photographs. Several of the defects produced by the test window shots appeared similar to the crime scene window defect.

The .22 bullet taken from the victim and several of the test bullets (collected by a cotton box) were examined by scanning electron microscopy/energy dispersive X-ray spectroscopy. The test bullets showed glass particles on and embedded in their surfaces. Particles of similar size and composition were found embedded in the surface of the bullet from the victim. The bullet likely struck the window prior to hitting the victim.

It was apparent by the morphology of some of the mushroomed test .22 bullets that they hit the window crack. These bullets showed that the glass on one side of a crack often fails before the other side during the strike. Aggregations of powdered glass on many of the mushroomed surfaces of the .22 bullets suggest that as the bullet mushrooms during impact on the window surface, the glass in contact with the bullet powderizes and coats the mushroomed surface of the bullet with a layer of fine glass particles.

KEYWORDS: forensic science, window glass, bullets, .22 caliber, scanning electron microscopy/energy dispersive X-ray spectroscopy

During the early morning hours of a mid-December day in a ground-floor apartment in National City, California, a middle-aged man was fatally shot with a single .22 bullet while apparently cleaning up pieces of a broken window. The window was broken from the outside approximately an hour earlier. The aluminum-framed window was half fixed and the other half, horizontally movable. The movable portion of the window had been broken in; the fixed half of the window was cracked, but no large pieces of that window appear to have fallen from its aluminum framing. An unusual defect, slightly above one crack in the fixed portion of the window was shown in two of the crime scene photographs (Figs. 1*A* and 1*C*). The window defect had no close-up photographs and no pieces from this window were collected for laboratory examination. At the time of the crime scene investigation, homicide investigators apparently decided that a bullet did not produce the window defect.

A mushroomed .22 bullet (Fig. 2*A*) was recovered from the victim at autopsy. The medical examiner's report described the fatal wound as "a single penetrating gunshot wound of the right chest which traveled from front to back and right to left injuring the aorta in two places and perforating both lungs." A firearms expert determined that the bullet was shot from a .22 Marlin rifle and there was evidence of at least two impact zones on the bullet. That same expert, addressing the possibility of a shot through the window, reported that he did not see glass fragments associated with the bullet. Examination of the bullet through a stereomicroscope by the author also did not reveal any recognizable particles of glass associated with the bullet.

The purpose of this paper is to describe how the unusual window defect was created by a .22 bullet, examine the interaction of .22 bullets with window glass, and by light microscopy and scanning electron microscopy/energy dispersive X-ray spectroscopy (SEM/EDS) characterize the association of glass fragments with .22 bullets that have been shot through window glass.

Materials and Methods

A used aluminum-framed, single pane window (glass thickness: 0.091 in. (2.29 mm)) was obtained from a window replacement firm. The window was cracked by a hammer blow to its edge and it was shot 23 times along the window cracks with a .22 Marlin Model 60 rifle using either CCI .22 caliber LR Mini Mag™ round nose copper-coated bullets (3 shots) or with Winchester-Western .22 LR round nose copper-coated bullets (20 shots). The rifle was approximately 90° to the surface of the window. All shots were within 0.25 in. (6.4 mm) of a window crack. The muzzle of the rifle for these shots was approximately 6 in. (15 cm) from the glass and the window was 4 ft (1.2 m) from a cotton filled collection box. Two control shots were made by duplicating all features described above except without the intermediate window glass.

The window glass, the questioned bullet, and test bullets were analyzed in an ETEC Autoscan scanning electron microscope equipped with a Kevex Delta II energy dispersive X-ray analyzer.

Results and Discussion

The Window

In some of the test shots, the defects produced in the window are circular with the preexisting crack at or near the center of the bul-

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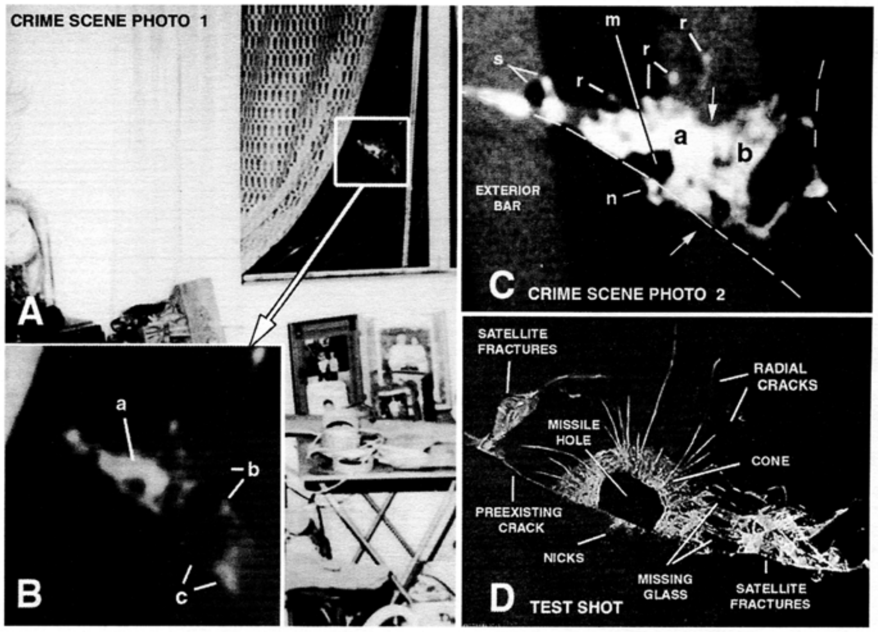

FIG. 1—A: *One of the two crime scene photographs that show the questioned window defect. The thin bar to the right of the defect is part of the window screen frame. To the right of the screen frame is the center bar of the window.* B: *Enlargement of the defect in the window shown in* A. (a) *Region corresponding to the cone produced by a bullet.* (b) *Possible area of satellite fracturing.* (c) *Possible area of satellite fracturing that was apparently lost before the second photograph was taken.* C: *Enlargement of the crime scene window defect taken from the second of the two photographs that showed the defect. There was an outside decorative wooden grillwork approximately 12 in. (30 cm) from the window, two bars of which can be seen in the photograph. Dashed lines represent apparent preexisting cracks in the window.* (a) *Region corresponding to the cone produced by a bullet.* (b) *Possible area of satellite fracturing. "m" Apparent bullet hole. "n" Possible nicks. "r" Possible radial cracks. The arrows mark the border between regions* (a) *and* (b). D: *Image of one of the test shots through the previously cracked window. A small portion of the glass to the left of the bullet hole along the preexisting crack fell from the defect and was digitally reconstructed. The bullet hole in this defect is larger than those produced by the other test shots. This defect was selected because of the extensive satellite fracturing.*

let hole. These defects have the typical cone and radial cracks, distinctive of a bullet's impact on window glass (1). In these shots, the bullets appear to have struck both sides of the glass on a crack.

The other shots in this experiment series produced a defect on only one side of the window crack. The cone and radial cracks did not transmit to the glass on the other side of the crack, producing a "rising sun" defect (e.g., Fig. 1*D*). This feature was created when the bullet hit only or mostly (see below) on one side of the glass near the crack. This is the situation that appears to have occurred for the crime scene window defect, where the presumed .22 bullet struck mostly above a preexisting crack in the window. One of the test defects (Fig. 1*D*) closely resembles the crime scene window defect.

In the crime scene window, the area marked "a" (Figs. 1*B* and 1*C*) corresponds to the cone region in the test window defect (Fig. 1*D*) and the radial cracks correspond to apparent radial cracks ("r" in Fig. 1*C*) in the questioned window defect. In addition, there are small nicks in the test window defect (Fig. 1*D*) below the preexisting crack near the bullet strike hole. The crime scene window defect shows similar apparent nicks ("n" in Fig. 1*C*). Satellite fractures occur in several of the test shots (e.g., Fig. 1*D*). These areas are found a short distance from the cone and have extensive fracturing within a confined area. The area of the satellite fractures may be relatively small (Fig. 1*D*, left) to fairly large (Fig. 1*D*, right). Some loss of glass may occur within the area of the satellite fractures at the time of the shot. It appears that in the crime scene window region "b" (Figs. 1*B* and 1*C*) is a satellite fracture area. There is likely an additional, smaller satellite fracture area to the left of the cone area ("s" in Fig. 1*C*).

The area of the questioned window corresponding to region "b" in the crime scene photograph (Fig. 1*B*) has a different appearance than that same region in the second crime scene photograph (Fig. 1*C*). The reason for the difference between the two photographs may be that depending on the camera and flash angle, satellite fractures reflect light back to the camera differently between photographs due to the angles of the fractures in the glass. A portion of the satellite fracture area in the lower right part of the first photograph of the crime scene window ("c" in Fig. 1*B*) does not appear in the second photograph of the crime scene window (Fig. 1*C*). Pieces of the defect likely fell from the window during the time between the two photographs.

The .22 Bullet

The mushroomed bullet (Fig. 2*A*) recovered from the victim at autopsy was reported by the medical examiner not to have hit bone.

The medical examiner testified that the bullet entrance hole in the victim appeared to be from a larger caliber (i.e., the bullet was likely mushroomed prior to striking the victim). It also appeared that the .22 missile had hit a second object after mushroom formation in that there is a scrape mark on the mushroom of the bullet (Fig. 2*A*-2).

Some of the test .22 bullets show the result of striking a window crack near the center of the bullet (Figs. 2*B*, 2*C*, and 2*D*). The breakage of the glass on one side of a crack before the other may result in a "step" feature in the mushroom of the bullet as shown in some of the test bullets (Figs. 2*B*, 2*C*, and 2*D*). These features on the bullets make it clear that one side of the glass on a crack is often more resistant to failure than the other. Usually, when the glass fails on one side of a crack, it goes all at once. However, a nonuniform failure may have occurred for the bullet shown in Fig. 2*D* in that this bullet rotated approximately 20° from center (Fig. 2*D*-3) before the first side of the glass on the crack failed. The second side of the glass failed with the bullet remaining at approximately the same angle.

Another of the test bullets (Fig. 2*E*) showed a particularly interesting result of a strike near the edge of the bullet at a window crack. For this bullet, as in the bullets shown in Figs. 2*B*, 2*C*, and 2*D*, the glass on one side of the crack failed before the other. However, in this case the bullet did not break free of the unbroken side of the glass until the bullet was scraped almost its entire length by the glass edge. Near the base of the bullet, the gouging by the glass edge deepened into the bullet (Fig. 2*E*-2, arrow) which apparently resulted in the glass edge breaking before the bullet was clear of the glass. Tool-mark-like striae are present (Fig. 2*E*-3, arrow). Most likely the scrape marks on the anterior portion of this test bullet were almost completely obliterated from friction by the cotton fibers of the bullet collection box.

Bullet/Glass Association

In the test shots through the window, the mushroomed surfaces of many of these bullets show regions of white powder (Fig. 2*D*-1, white arrow; Fig. 2*E*-1, white arrow, and Fig. 3*A*). Particle sizes range from less than 0.5 to almost 20 μm (Fig. 3*B*). Analysis by EDS reveals these particles to have the same composition as that of the test window glass (see Fig. 5*C*). Scanning electron microscopical examination of one of the mushroomed test bullet's surface shows the fragments of glass (Figs. 3*C* and 3*D*), some of which are embedded in the bullet's lead surface (e.g., Fig. 3*D*, asterisk).

The two control bullets shot without the intermediate window glass were not mushroomed nor did they have glass or any substances resembling glass associated with them.

The .22 bullet from the victim was examined in the SEM within the area circled on the bullet in Fig. 2*A*. Particles were found em-

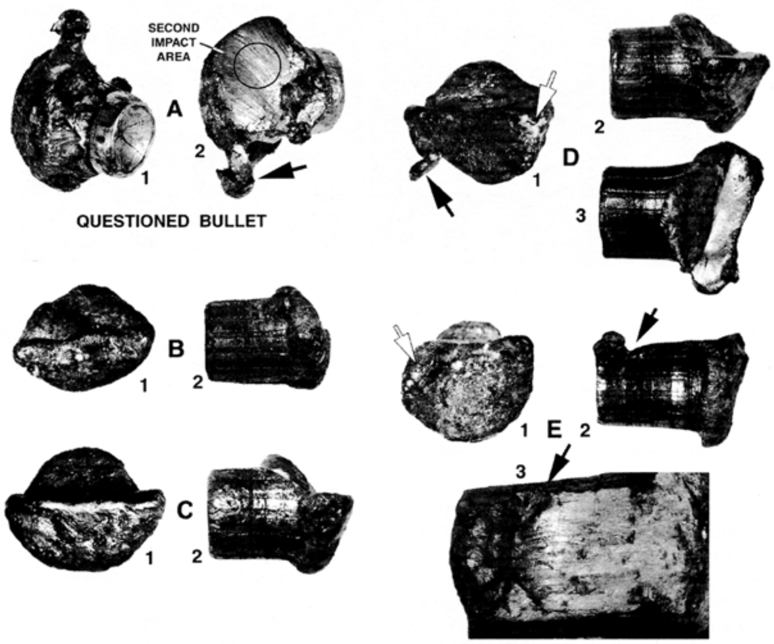

FIG. 2—A: *The .22 bullet taken from the victim at autopsy. Circle: area examined by SEM/EDS. Arrow: lead spur.* B: *Test .22 bullet that was shot through window glass at a crack.* C: *Test .22 bullet that was shot through window glass at a crack.* D: *Test .22 bullet that was shot through window glass at a crack. White arrow (on* D-*1) points to a concentration of powdered glass. Black arrow (on* D-*1) points to a lead spur. The bullet shown in* D-*2 is rotated 90° in* D-*3.* E: *Test .22 bullet that was shot through window glass at a crack. White arrow (on* E-*1) points to a concentration of powdered glass. Black arrows (on* E-*2 and* E-*3) indicate a dip in the gouge into the bullet body caused by the window glass. The scrape area of bullet shown in* E-*2 was rotated 90° and enlarged in* E-*3.*

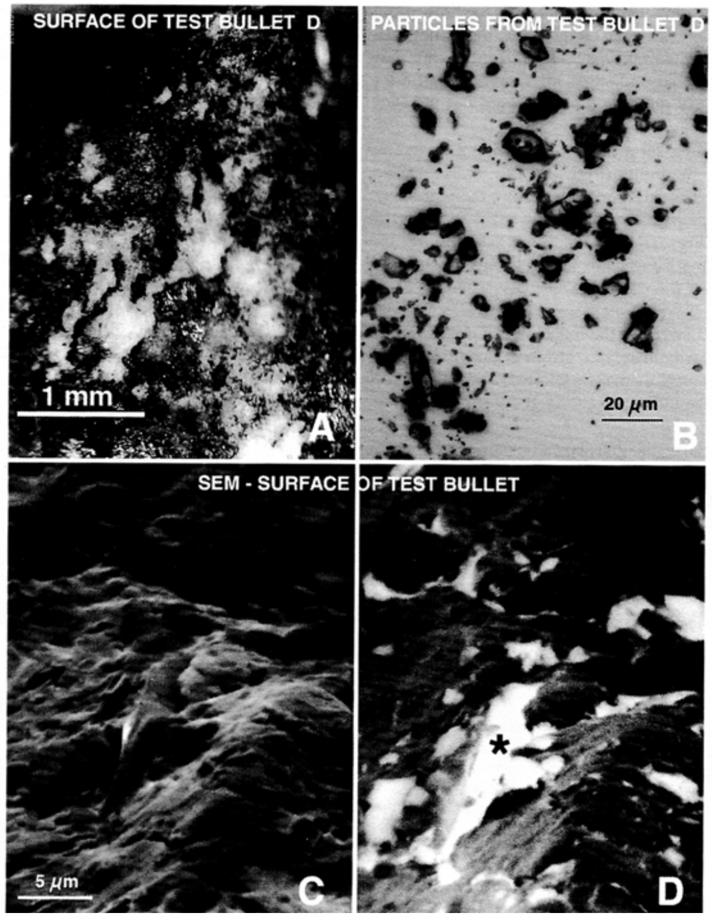

FIG. 3—*Observations of the bullet and associated particles from the test window shots.* A: *A concentration of powdered glass from an area on a test bullet. Even at a magnification of 70× through a stereomicroscope, individual glass particles could not be resolved.* B: *A portion of the sample from the powder that was spread onto a slide and imaged through a compound microscope. By SEM/EDS, these same particles were identified as window glass.* C: *Scanning electron microscope—secondary electron image of the surface of a test .22 bullet that was shot through a window.* D. *The same area and magnification as* 3C, *but a reverse backscatter electron image. The white features (low backscattering relative to the bullet's lead surface) are glass fragments, one of which is embedded (asterisk) in the lead.*

bedded in the bullet's lead surface (Figs. 4*A* and 4*B*). Spectra (e.g., Fig. 5*A*) taken of these particles show that they have essentially the same composition as that of the window glass fragment found at the crime scene (Fig. 5*B*). Glass from both the test window and the crime scene window have similar compositions (Figs. 5*B* and 5*C*). Comparison of a spectrum of a glass particle embedded in a test bullet (Fig. 5*D*) with a particle embedded in the victim's bullet (Fig. 5*A*), also show a close similarity. It is likely that the embedded particles in the victim's bullet are from the crime scene window glass.

Rebuttal to the evidence of glass particles associated with the questioned bullet was presented by an opposing expert who noted that the questioned bullet was mounted with clay by him for observation under a comparison microscope. That expert opined that fragments of the mounting clay on the bullet were being mistaken for the glass particles. (Attempts by the author to obtain a sample of this clay for confirmation of his hypothesis were futile.) Another expert, whose specialty was SEM/EDS, testified that the particles on the questioned bullet were not likely glass since "silicon is everywhere" in the environment.

Three recently purchased (ca. 1996) samples of modeling clay, one of which was used for bullet mounting in a comparison microscope in the author's laboratory, were analyzed in the scanning electron microscope with a beryllium-window energy dispersive X-ray analyzer. All these samples showed calcium without other elements (Fig. 6*A*). Four samples of a clay-like substance found in the metal bullet mounts of an approximately 50-year-old B&L comparison microscope all showed varying amounts of silicon and magnesium (likely talc), sulfur, chlorine, and calcium (e.g., Fig. 6*B*). Calcium predominates in all of these samples. There is no similarity between the spectra of window glass (e.g., Fig. 5*B*) and that of any of the clay and clay-like samples.

Reconstruction

The victim's bullet appears to have an additional impact zone (Fig. 2*A*-2), the origin of which could not be accounted for by any object at the crime scene or from the clothing worn by the victim. An opposing expert posited that the bullet's second impact was by

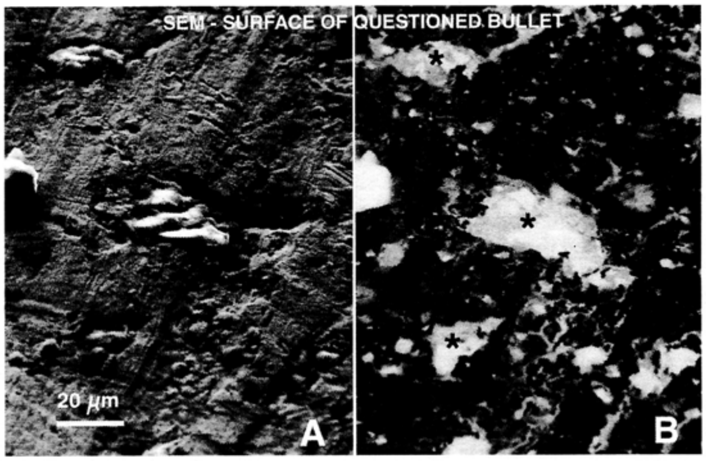

FIG. 4—*Scanning electron microscopy of the .22 bullet from the victim in the region of the second impact zone (within the black circle in Fig. 2*A*).* A: *Secondary electron image.* B: *The same area as* A, *but a reverse backscatter electron image. The white features (low backscattering relative to the bullet surface) appear to be glass fragments and tissue debris. The apparent glass fragments (asterisks) are embedded in the surface of the lead.*

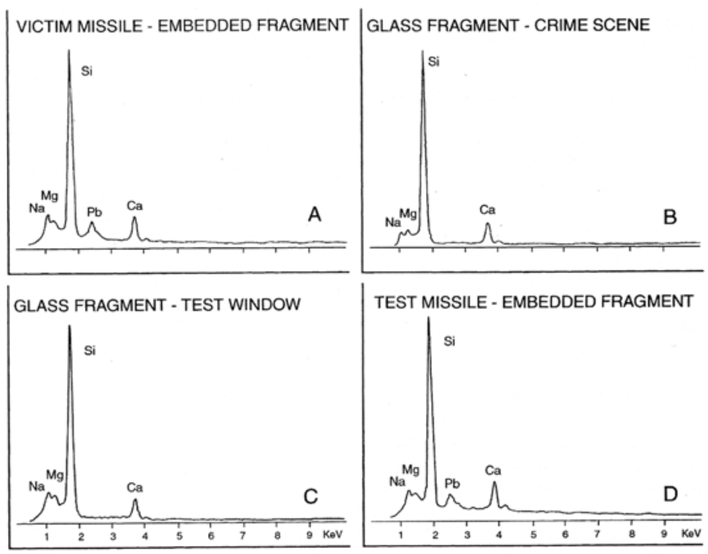

FIG. 5—*Energy dispersive X-ray spectra.* A: *Spectrum of an apparent embedded glass fragment from the victim's bullet.* B: *Spectrum of a glass fragment recovered from near the crime scene window.* C: *Spectrum of a glass fragment from the test window.* D: *Spectrum of an embedded glass fragment from a test bullet.*

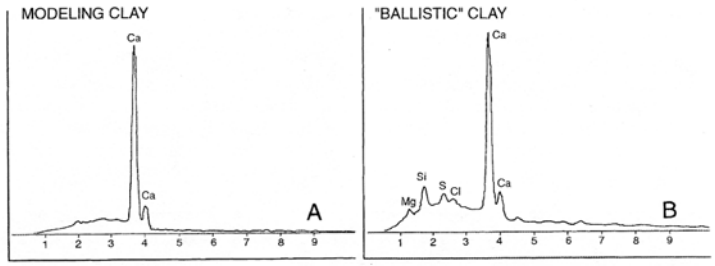

FIG. 6—*Energy dispersive X-ray spectra.* A: *Spectrum of a cream-colored modeling clay used for bullet mounting in the Forensic Science Consulting Group's laboratory, Cardiff, California, 1996 through 1998.* B: *Spectrum of a clay-like substance found in the metal bullet mounts of an approximately 50-year-old B&L comparison microscope.*

a hit on bone despite the medical examiner's report that the bullet did not hit bone. A bone strike scenario is also unlikely because bone particles were not found associated with this defect. However, the bullet striking a crack in the window may account for the second impact zone.

The morphology of the test bullets that had interacted with the cracked window glass provides an explanation for the second apparent impact on the victim's bullet. Like the test bullet shown in Fig. 2*E*, the interaction of the victim's bullet with cracked window glass created the appearance of a second impact area on that bullet. Fragments of glass were embedded in the second impact surface of the bullet, either from the glass edge that scraped the bullet or glass particles were transported from the mushroom area. Unlike the test bullet shown in Fig. 2*E*, a smaller portion of the victim's bullet overlapped one side of the crack. When the side of the glass failed where most of the victim's bullet hit, the unbroken glass on the other side of the crack (Figs. 1*B* and 1*C*) provided the scraping surface to produce the appearance of a second impact on the bullet. The second strike of the victim's bullet was at approximately 45° to the first. Although none of the test bullets rotated this much, the test bullet shown in Fig. 2*D* rotated approximately 20° on the glass before the first side failed, thus showing that a .22 bullet can rotate during a strike on glass.

An alternative scenario is that the victim's bullet hit an object between the window and the victim and did not interact with the unbroken side of the window defect. The glass fragments in the second impact zone originated from the initial impact with the window and these particles were dragged into the second impact zone during the interaction with the second object. However, if the bullet went through window glass and ricocheted off an object, then one would expect particles on the bullet's surface from the second object. No inorganic particles other than glass were observed on the second strike surface of the victim's bullet nor, as noted previously, was there any indication of an object at the crime scene from which the bullet could have ricocheted.

Regardless of the origin of the second impact area on the victim's bullet, the bullet that struck the victim came through window glass. The bullet impacted the window slightly above a preexisting crack and created the crime scene window defect. A scrape mark on the bullet, indicative of a second impact, was made either by the bullet interacting with the unbroken portion of the crack in the window or, less likely, the bullet hit and ricocheted off an unidentified object prior to hitting the victim.

Conclusion

It is apparent that for a previously cracked window, the form of the window glass defect caused by a bullet strike will vary depending upon where the strike occurs in relation to the crack. Swansen et al. (2) note that the order of shots through window glass can be determined if the radial cracks caused by one shot stop at the radial cracks of another. Miller (1) notes the same phenomenon with nonbullet-generated window cracks. The form of the defects observed in a number of the test shots through the previously cracked window (e.g., Fig. 1*D*) adds an observation: not only do the radial cracks stop at a previous crack in a window, but also may the cone. In addition, satellite fractures may occur associated with the bullet-generated window defect.

When a .22 missile strikes a window on a preexisting crack, the glass on one side of the window crack may fail before the other side. If the bullet strike on the window crack is near the center of the bullet, then that bullet may pick up an impression of the window crack or, in many cases, generate a step-like morphology (e.g., the bullets shown in Figs. 2*B*, 2*C*, and 2*D*). In a similar study, Bell (3) observed impressions of cracks in the noses of .38 Special full metal-jacketed bullets that went through previously cracked tempered glass. If the .22 bullet strikes a crack near the bullet's edge, then the unbroken side of the glass may scrape that bullet, generating the appearance of an additional impact (e.g., the bullet shown in Fig. 2*E*). The uniform depth of the step marks in the bullet across the mushroom (e.g., Figs. 2B, 2C, and 2E) suggests that when one side of the glass fails, it often goes all at once. However, a nonuniform failure of the one side of the glass on a crack may account for the angled step defect that is shown by the test bullet shown in Fig. 2*D*.

An occasional feature of a .22 bullet that hits glass is the creation of a lead spur on the mushroom of the bullet (e.g., Fig. 2*D*-1, arrow). This appears to be created by a small lead flow away from the main body of the mushroom during the bullet's strike on the window. The victim's bullet has a lead spur (Fig. 2*A*-1, arrow).

Extensive glass fragmentation (powderization), which likely forms a layer on the mushroom surface of the .22 caliber bullet, occurs where there is intimate contact of window glass with the bullet during the strike. Remnants of the powdered glass layer are shown in Figs. 2*D*-1 and 2*E*-1 (white arrows). Relatively large glass fragments were never observed on the test .22 bullets. This

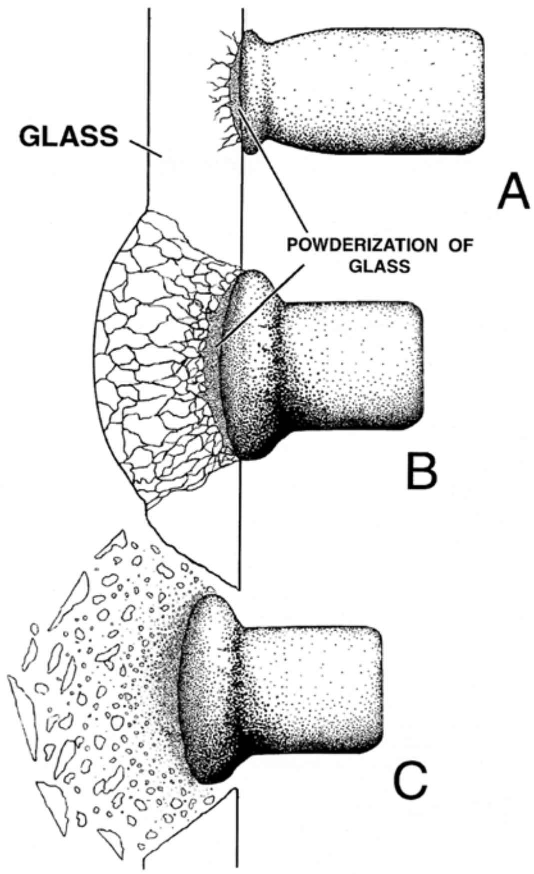

FIG. 7—*Proposed sequence of events when a .22 bullet hits window glass.* A: *Early in the contact of the bullet with the glass. Simultaneous with the start of mushroom growth is the generation of fine glass fragments associated with the mushroom.* B: *The bullet at completion of mushroom formation and glass failure.* C: *The bullet breaking through the glass with the generation of large glass fragments. Not to scale.*

adds an aspect to the interaction of .22 bullets with window glass that has not been previously reported. The creation of a powdered glass layer on the bullet surface may not occur for other calibers and/or bullet types. For instance, Bell (3) observed glass fragments on full metal-jacketed .38 Special bullets without the assistance of SEM/EDS, suggesting that these bullets came into direct contact with relatively large glass fragments, perhaps without the generation of a layer of powdered glass on the bullet. Moreover, Miller (1) notes that, "glass particles may be expected to be embedded in a lead or copper jacketed bullet which penetrated glass." The present study makes it apparent that even though a bullet goes through window glass, recognizable associated glass fragments may not be observed when that bullet is examined solely by light microscopy. Indeed, DiMaio (4) stresses the need to examine such bullets with SEM/EDS.

A summary of the bullet interaction with window glass is given in Fig. 7. A .22 bullet is shown early in a strike on window glass in Fig. 7*A*. The window glass at the bullet contact does not fail immediately, but remains intact long enough for the mushroom to form. With the mushroom formation, the high pressure and temperature imparted by the bullet into the glass, powderizes the glass directly associated with the bullet mushroom. When the pressure on the glass reaches a critical point, the glass fails (Fig. 7*B*). The final stage is the punching of the bullet through the window with the creation of relatively large glass fragments in front of the powdered glass layer and the cone-shaped defect in the window (Fig. 7*C*). In this scenario, the .22 bullet does not come into contact with the large glass fragments at the time of passing through the window glass.

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