Article

A New Method for Documenting Hertzian Fractures in Glass Windows

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Abstract: Hertzian fractures, or cone fractures, caused by bullet perforations in glass windows can be useful in shooting incident reconstruction. However, they are difficult to photograph because of the transparent nature of glass. Standard glass documentation photographs prohibit determination of the deflection direction of light rays off fracture features, thus creating difficulty in determining the cone-bearing surface of the Hertzian fracture. This article presents a new method for photographing these fractures on various glass materials. Surface reflection photography (SRP) documents the contour-dependent nature of the surface and fracture, allowing the shooting reconstructionist to determine the bevel-bearing surface of the glass from the collected images without direct observation of the glass material. This method is applicable for annealed, tempered, laminated, and coated glass materials with both light and dark backgrounds.

Introduction

Multiple fracturing mechanics appear when a high-velocity projectile, such as a bullet from a firearm, impacts on glass. In addition to the radial and concentric fracture lines that occur, there is localized damage to the glass in the vicinity of the impact site [1, 2]. Hertzian fractures in glass, also known as Hopkinson fractures, cone fracturing, coning, cratering, or beveling, are a well-known phenomenon amongst forensic firearm analysts, forensic glass analysts, and crime scene documentation and reconstruction experts [2–7]. Observation of the position of the bevel-bearing surface can be used to determine the direction of travel of the projectile [8].

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When a bullet contacts a glass surface, compression shock waves radiate from the point of impact [2]. These compression shock waves travel through the glass along a spherical wave front, originating from the impact face of the glass. Once the shock waves reach the opposite face of the glass, they are reflected back toward the impact face of the glass and reversed into tension waves. From an engineering perspective, glass is strong under compression but weak under tension [2]. The powerful tension shock waves break the glass into thin flakes. These flakes are ejected from the surface as the shock waves propagate through the glass, as well as cleared from the central impact point as the bullet perforates the object. Figure 1 is a diagram of the general cross-sectional profile of a Hertzian fracture. It is important to note that outside the Hertzian fracture mold, the void left behind after ejection of the flakes, the glass retains its initial surface texture on both sides [9]. The impact face, or entrance side of the glass, suffers little damage other than the glass that is removed by bullet perforation and some additional back-chipping of the bullet perforation.

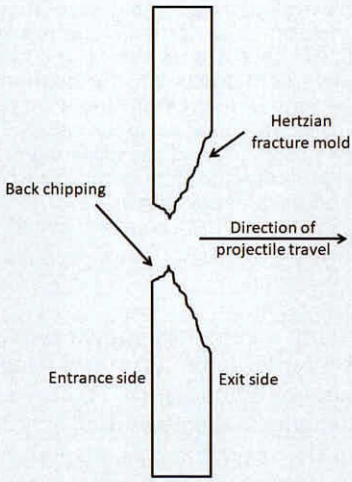

Figure 1

Cross-sectional diagram of a Hertzian fracture created by perforation of a glass pane by a projectile moving left to right. The right face of the diagram exhibits the conical-shaped void associated with the Hertzian fracture mold.

Two challenges in shooting reconstruction work are (1) the determination of the direction of travel of the projectile and (2) the documentation of the fracture data relevant to the analysis. Because broken glass is one of the most fragile types of physical evidence, it may not be possible for a shooting reconstruction expert to view all the necessary fracture elements in situ at the crime scene. Although written documentation of physical observations of the glass is required, additional photographic documentation is ideal for numerous reasons including inside and outside window orientation, display of scale, improved accuracy of description, and aesthetics for court presentation.

Few specialized techniques exist for photographically capturing the beveled shape of these fractures in glass panes. Haag and Haag successfully demonstrated high oblique angle photographs of the Hertzian fracture mold [8]. Young proposed a darkfield method for photographing fractures in glass, contrasting a dark background against light scattering off the glass fracture surfaces [10]. Although the darkfield method is excellent for visualizing the fractures, it does not discriminate against the originating surface of the light scattering. A major impediment to imaging features on the surface of, or interior to, a glass material is its transparent and reflective properties. Rough features, both on the surface and interior to the object, deflect incoming light rays. This allows a camera to capture images of glass fractures such as those shown in Figures 2a and 2b. Normally, radial and concentric fractures span the thickness of the glass, so photographs of the light deflection off these fractures is relatively easy to accomplish. However, light deflections from the Hertzian fracture mold are surface specific. When glass is transparent, photographs captured from either side of the glass of the light deflections off the fracture surfaces may appear indistinguishable because deflected light rays may reach the camera regardless of their originating surface. This makes it difficult to determine on which side the fracture is located. For example, in Figure 2a, determining whether the fracture beveling is on the near or far side of the glass with respect to the camera from glass fracture image data presented presents an enormous challenge.

This article describes another method for photographing the beveled contour of Hertzian fractures in glass arising from bullet perforation. For simplicity, this paper will refer to this method as surface reflection photography (SRP). SRP is an additional step in the documentation process, allowing the photographer to collect surface contour data that elucidates characteristics of the Hertzian fracture necessary for proper interpretation. The series of photographs created using SRP allows the reconstruction expert to identify on which side of the glass the fracture beveling is located, and thus determine the direction of travel, without having to physically examine the object or guess which glass surface is closest to the camera using standard fracture documentation photographs. The balance of the article will illustrate the background and practical components of the method, as well as show application in various conditions and glass materials.

Method

This section presents the specific equipment and methodology used to collect the data presented in this paper. However, because the modern photographer's arsenal is nearly limitless in terms of the types and variety of equipment available, there are many proper ways of setting up the SRP method using other equipment. Photographs were taken using a Nikon D90 camera equipped with a Nikon 18-105 mm lens and an SB-600 flash unit, mounted on a standard tripod. A remote shutter release cable was used to further ensure camera stability. The flash unit, with the built-in diffuser deployed, was triggered via a flash sync cable.

Glass materials that were used exhibited variations in thickness, as well as different manufacturing characteristics. Testing was performed on eight annealed glass panes (1/8″ thickness, uncoated, and 1/4″, both coated and uncoated); 50 tempered glass panes (1/4″ thickness, uncoated and semicoated), and two laminated glass samples (standard U.S. passenger vehicle front windshields). The coated glass was created by applying a single layer of automotive glass polymer tint to one face of the glass. Annealed and tempered glass samples were supported in a home-built metal frame, attached to wooden uprights. Additionally, to prevent the tempered glass from collapsing after perforation, a portion of the panes was wrapped with clear contact paper out to and around the edges, and a hole was cut in the center, before insertion into the support frame. The laminated glass windshields were unsupported on their edges. Glass was shot

at a distance of approximately 25 feet with a semi-automatic pistol firing 9 mm Luger ammunition (115 grain FMJ). Sticky labels were applied to each surface of the glass in proximity to the bullet perforation to measure scale.

Most of the glass was photographed on the firing range of the Utah Bureau of Forensic Services Northern Laboratory. A few objects were photographed in the storage area and outside to test the effect of background brightness on image quality and ability to determine surface flatness. The camera was positioned approximately 2 feet from the damaged glass with a lens focal length of ~50 mm. In most cases, the camera was placed directly in front of the fracture, nearly perpendicular to the surface. In some cases, in order to position the flash unit properly and capture its reflection, the tripod had to be offset to one side of the fracture and angled slightly. Photographs were taken with manual focus to ensure that the focus was on the glass front surface and not the background. Medium to small apertures (e.g., f/14–f/22) were used to create a long depth of field to ensure the entire fracture was in focus. The shutter was synced to the flash unit, and a lower sensitivity ISO was selected (100–400 range). The flash unit was set to fire in TTL mode with no additional flash or exposure compensation.

Standard images of the glass fractures were taken prior to setting up for the SRP method by illuminating the pane at an oblique angle with the camera flash from a distance of approximately 3 to 4 feet. I found the best method for positioning the flash for taking SRP images was using live video from the camera and a penlight. A small flashlight was strapped to the top of the flash head. Like most modern digital cameras, the Nikon D90 has a live view video mode standard on the camera, allowing the photographer to see the subject on the LCD screen rather than looking through the viewfinder. After activating the live view, the flash unit was placed next to the camera lens and moved until the penlight reflection was observed in the video. The flash was positioned so the flash image would overlap the glass in the desired position. Multiple photographs of the fracture were collected by moving the flash unit around the perimeter of the beveling. This process was repeated for both sides of the glass. After completely photographing the accessible surfaces of the glass object, the images were analyzed visually to determine qualitatively where the discontinuities in the flash image occurred with respect to the fracture features.

Results

Figure 2 compiles examples of photographs of a single Hertzian fracture taken from the entrance and exit sides of a 1/4″ uncoated annealed glass pane. The standard glass fracture images (Figure 2a, 2b) depict the radial and concentric fractures in the bulk of the glass, with a Hertzian fracture, approximately 63 mm diameter, with an oblong perforation in the center approximately 20 mm in diameter. Images collected using the SRP method are shown in Figures 2c and 2d. In the entrance side SRP image (Figure 2c), the image of the flash is visible up to the edge of the bullet perforation. There is 4 mm of back-chipping visible on the upper edge of the fracture depicted. The flash image can be seen up to the edge of the bevel in the exit side SRP image with 13 mm distance between the light source image and the perforation (Figure 2d). Composite SRP images of the Hertzian fracture were created by layering seven entrance surface images (Figure 2e) or 12 exit surface images (Figure 2f) together using open source image editing software (GNU Image Manipulation Program, version 2.8.20). Figure 2e shows surface reflectance data using the SRP was collected for approximately 73% of the center perforation circumference; Figure 2f has approximately 93% data coverage for the outer edge of the Hertzian fracture mold. Both composite SRP images confirm what is observed in the single SRP images.

The same imaging effect is visible in other manufactured glass products. Figure 3 shows standard glass fracture images and SRP images of the entrance and exit sides of a 1/4″ uncoated tempered glass pane. This glass is equivalent to the pane in Figure 3 except for the tempering treatment. All of the dicing fractures are visible in the fracture documentation images (Figures 3a, 3b). The edges of the Hertzian fracture can be observed on the entrance (Figure 3c) and exit (Figure 3d) faces of the tempered glass pane in the SRP images. The entrance side exhibits 1–2 mm of back-chipping around the perforation, and the exit side shows the beveled region is a ring of approximately 18 mm thickness. The entrance (Figure 4a) and exit (Figure 4b) SRP images of an automobile windshield exhibit similar reflection patterns as shown previously.

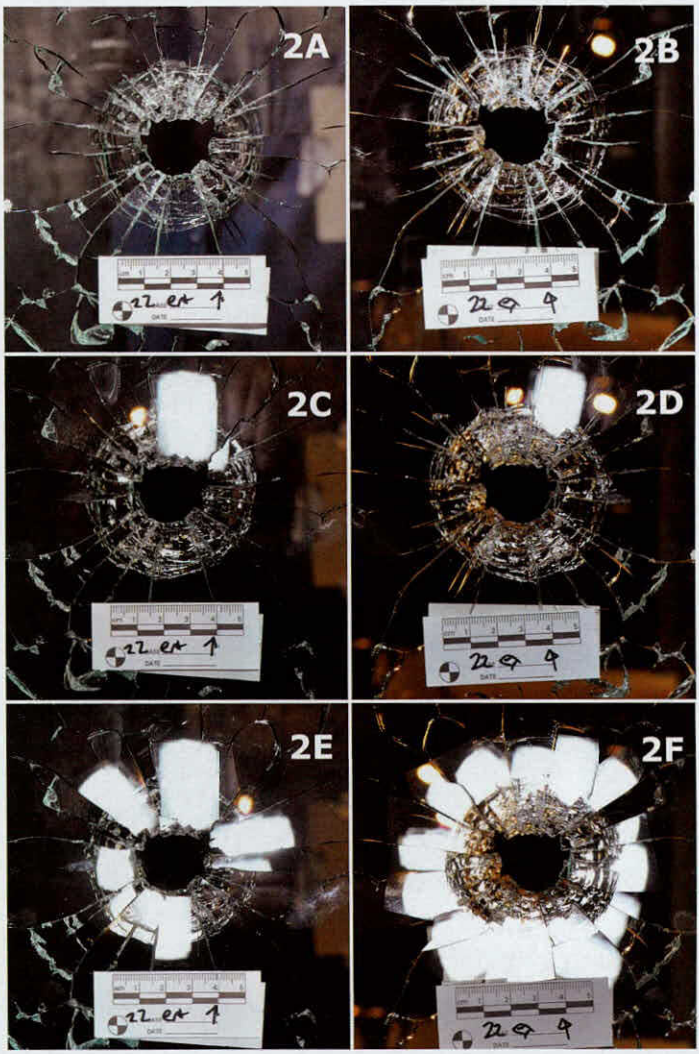

Figure 2

Photographs of a Hertzian fracture in an annealed glass pane: (a) oblique lighting image of bullet entrance surface; (b) oblique lighting image of bullet exit surface; (c) SRP image of entrance surface, narrow ring of unlit glass adjacent to image of flash highlights back-chipping; (d) SRP image of exit surface, wide ring of unlit glass adjacent to image of flash highlights fracture beveled region; (e) 7-photograph composite SRP image of entrance surface; (f) 12- photograph composite SRP image of exit surface.

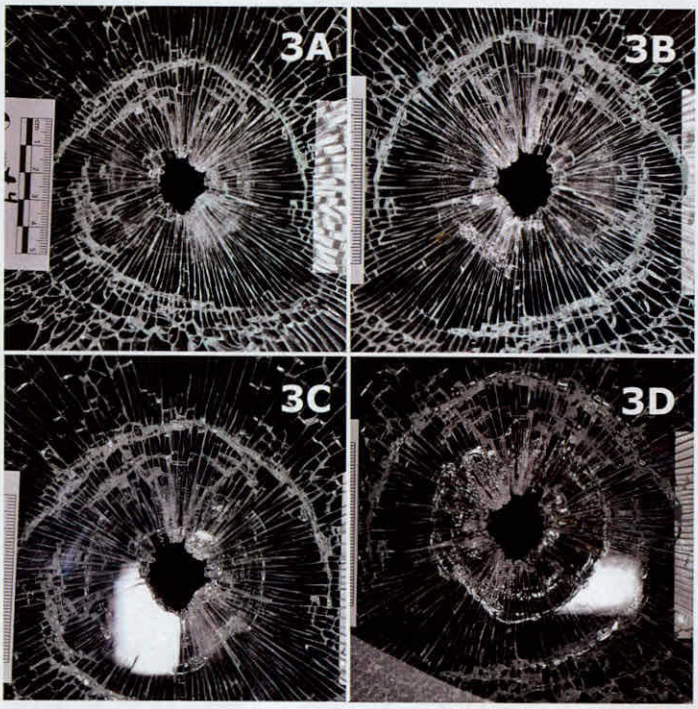

Figure 3

Photographs of a Hertzian fracture in a tempered glass pane: (a) oblique lighting image of bullet entrance surface; (b) oblique lighting image of bullet exit surface; (c) SRP image of entrance surface; (d) SRP image of exit surface.

A single 1/4″ annealed glass pane was covered with a piece of automotive tinting to test the effect of window coatings. The pane was oriented such that the polymer film was covering the exit surface of the glass. The resulting SRP images are shown in Figure 5. Although the perforation shows a clear hole, the polymer film trapped flaked glass between the pane and coating on the exit side (Figure 5b). The image of the flash is visible on the entrance side in Figure 5a up to the back-chipped edge of the perforation. On the exit side, the image of the flash exhibits disruption 18 mm from the perforation edge.

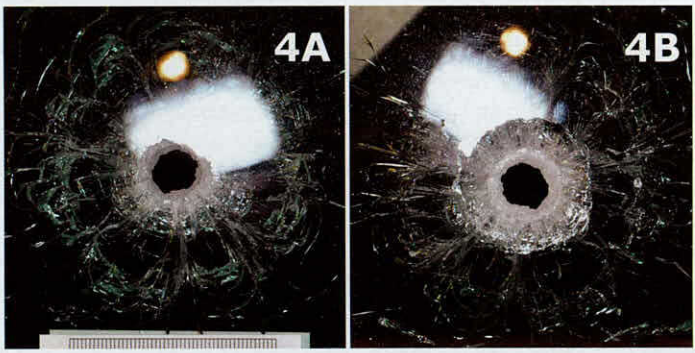

Figure 4

SRP images of Hertzian fracture in a laminated glass windshield: (a) image of bullet entrance surface; (b) image of bullet exit surface.

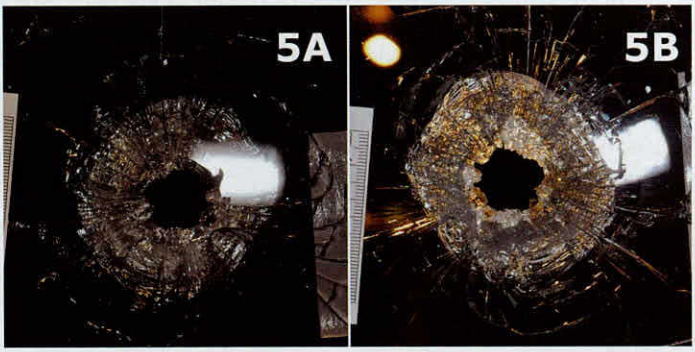

Figure 5

SRP images of Hertzian fracture in an annealed glass pane with automotive tinting applied to the bullet exit surface: (a) image of bullet entrance surface; (b) image of bullet exit surface.

Figure 6 includes the entrance (Figure 6a) and exit (Figure 6b) SRP images of a 1/4″ tempered glass pane, similar to the glass depicted in Figure 3. A light-colored wall was introduced behind the glass to change the brightness of the background compared to a dark background. Despite the lighter color, the flash reflection is still visible in the SRP images of the entrance and exit surfaces.

Discussion

Some crime scene personnel would call these "poor" photos because the reflection of the flash is captured in the image. However, these images are not Type I documentation photographs as discussed by Witzke [11]. Instead, they are Type II images designed to collect scientific measurements. The SRP images become data in an analytical method designed to qualitatively measure the flatness or smoothness of the glass surface around the edges of the Hertzian fracture. The proposed SRP method highlights the position of the flat portions of glass surrounding the Hertzian fracture mold by photographing the reflection of a strong light source. Although most light is transmitted through smooth-texture glass materials, they reflect a small portion of incident light from the surface based on the refractive index difference between glass and air, resulting in glare [12]. Clarity and magnification of the reflections are a function of the glass surface texture and contour and the background brightness. For a normally smooth glass surface, such as a window or a windshield, a discontinuity in a reflected light source image demarcates a physical boundary where the glass changes surface angle or smoothness. Therefore, an analysis of the position of the reflected light source discontinuity, relative to the central perforation and edges of the Hertzian fracture mold visible in standard photographs, reveals the perpendicular directionality of bullet travel through the material (entrance or exit direction but not angularity).

Consider four distinct areas of the SRP image of the entrance side, or impact side, of the fracture in Figure 7a, which shows an enlargement of the surface reflection portion of Figure 2c. From outside to inside the fracture, they are (1) outside the Hertzian fracture, (2) within the beveled region, (3) the perforation, and (4) the back-chipping. The first area is the top section of the image of the flash, lying outside of the Hertzian fracture mold, where the smooth glass reflects light back to the camera. The second area is the portion of the image of the flash overlapping

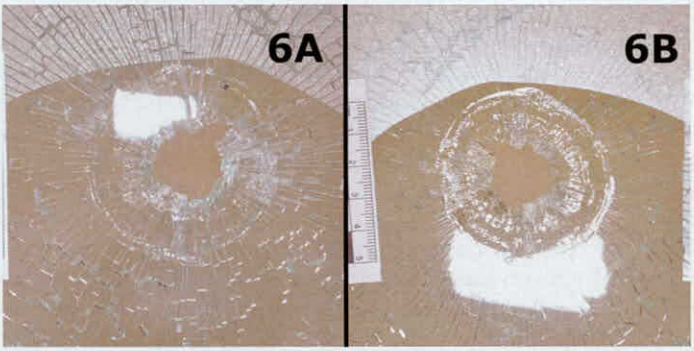

Figure 6

SRP images of Hertzian fracture in a tempered glass pane with light, backlit background: (a) image of bullet entrance surface; (b) image of bullet exit surface.

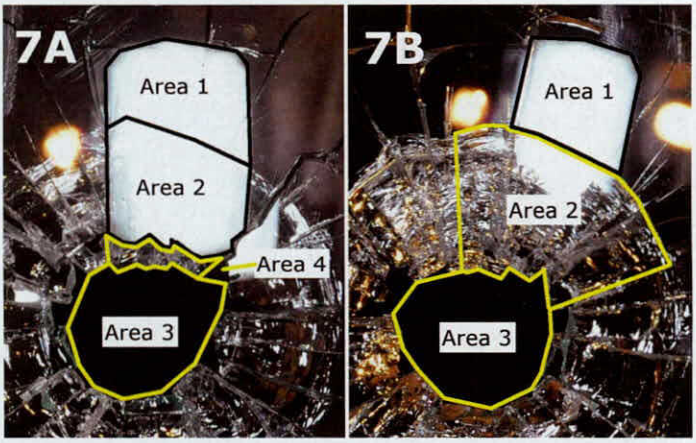

Figure 7

Annotated enlargements of SRP illumination from: (a) Figure 2c showing 4 entrance surface light deflection areas; (b) Figure 2d showing 3 exit surface light deflection areas.

the beveled region of the glass void on the opposite side. The reflected image appears continuous and smooth with the flash image outside the fracture because the glass surface is smooth on the entrance or impact side within the boundary of Hertzian fracture. There is a loss of intensity on the right and left edges where secondary light deflections off the opposite side (exit) of the glass are lost because of the rough surfaces caused by the glass spalling. Figure 2c also shows a small, offset reflection, located in the lower right portion of the image of the flash, produced by a deviation in the glass pane caused by a radial fracture. The glass on the right side of the radial fracture has a slight angle difference than the left, causing a secondary flash image to appear.

The remaining two areas are characterized by a lack of light, rather than brightness. Obviously, the central perforation has no material so light is passed directly through without reflection. Finally, there is the narrow back-chipping section between the perforation and the edge of the visible flash image. The back-chipping is roughly textured and at a different angle than the surface, scattering the majority of light rays away from the camera lens, leaving the glass visible, but not bright like the direct reflection.

Similarly, the SRP image on the exit surface is represented by three areas: (1) outside the Hertzian fracture mold, (2) within the beveled region, and (3) the perforation. Different from the entrance surface, the only one of these with a bright reflection of the flash is the region outside of the Hertzian fracture (Figure 7b). As seen in the entrance surface images, light from the flash overlapping the central perforation passes through the center without scattering. However, between the central perforation and outside the fracture, the beveled region of the fracture, the light is scattered away from the camera, leaving the glass visible and creating a discontinuity in the flash image. Thus, the shooting reconstructionist can easily distinguish the entrance and exit sides of a bullet perforation by observing the relative positions of the reflected light source image discontinuities.

The examples presented highlight some of the challenges with interpreting SRP images. Figure 7b shows a section of bright reflection extending into the Hertzian fracture mold, with 15 mm of the beveled region without a bright reflection. This same region in Figure 2b shows fracturing out to 22 mm from the perforation edge. It is important to note that the SRP method detects the presence of smooth, flat glass exterior surfaces,

not where the glass is damaged internally and has not changed the surface angle or the surface texture. Radial and concentric fractures that do not cause the opposite sides of the glass to separate and change position will show a smooth, continuous flash unit image. In Figure 7b, the flash image can be seen overlapping the fracture by approximately 7 mm (compared to Figure 2b). Although the glass has broken internally via the Hertzian fracture mechanism, flakes on the outside edge of the fracture may not all detach themselves from the original surface. Thus, the glass still appears flat at those points, but badly damaged; a needle could easily dislodge the flakes clinging onto the edge.

The fracture pattern shown in Figure 3 also exhibits some interesting features. Figures 3a and 3b show a dark spot in the center, associated with glass cleared by the perforating bullet, and well-illuminated circular features surrounding the fracture, visible between 24 to 38 mm from the perforation. Because of the density of radial fracture lines emanating from the central perforation, the surface features from the Hertzian fracture are partially obscured and less obvious than features exhibited in Figure 2. The observer might mistakenly believe that these arcs surrounding the perforation are the edges of the Hertzian fracture's beveled region. However, it is clear from Figure 3d that the glass surface is flat beyond the edge 18 mm from the perforation. These arcing features are concentric fractures, artifacts likely caused by the method for constraining the glass pane to the experimental rigging, and not associated with the Hertzian fracture or its interpretation.

This highlights two important factors regarding the collection and interpretation of SPR images. First, it is valuable to collect a series of images mapping the entire perimeter of the Hertzian fracture, and not just one small section. This series of images should focus on illuminating the boundary edge of the beveled region and central perforation. The qualified shooting reconstruction expert can analyze the series of images individually. Alternatively, the images can be combined using image editing software, as shown in Figure 2, for analysis or presentation aesthetics. Second, the directionality determination should consider the relative position of all the light source image discontinuities from the entire series of images, including documentation images. Figures 2c and 2d represent one of eight entrance side images, and one of 13 exit surface images, collected for the bullet perforation presented here. The summative effect of considering all the data, as seen in Figures 2e and 2f, can

account for imaging inconsistencies such as the aforementioned failure to remove glass chips out to the full edge of the Hertzian fracture mold, or multiple bright reflections where glass shards have become misaligned across radial fractures.

The results are equally dramatic and as easily interpreted for the tempered glass (Figure 3) and laminated glass (Figure 4) products tested. This method is particularly useful for tempered glass because of the extreme fragility of the dicing fractures. Frequently, only a fraction of the fracture would remain in an uncoated, tempered window, and the delicate nature of the evidence would dissuade contact with the glass. The SRP method is nondestructive and does not require physical contact with the glass. Additionally, the SRP method can be performed with photographic equipment regularly available to the crime scene investigator. This means that the images are collected on scene, without having to carefully transfer the glass evidence back to a lab for expensive or lengthy analysis.

Although various types of light sources could be used in the SRP method, the best light sources are high intensity with a relatively flat intensity profile. High intensity is required to overcome the small reflectance percentage of the air-glass interface. A through-the-lens (TTL) metered flash unit is ideal. If the light source and camera are not directly communicating real-time exposure information, the photographer must manually correct for exposure of the light source reflection relative to the rest of the information contained in the glass and fractures. With a TTL flash unit, the camera will limit the flash duration to only the time necessary to provide a sufficient exposure to keep the glass and the background properly illuminated. This is important because the reconstructionist will need to see the fracture edges in the SRP images to correlate with the fracture edges in the documentation photographs. In Figure 6, the image of the flash and the radial and dicing lines are clearly visible against the lighter background. The TTL flash unit provides a bright white reflection that contrasts well against most backgrounds including blue sky (data collected but not presented).

Another crucial element of the SPR method is inclusion of scale in the image series, both a measurement scale and a calibration image of the reflected light source image. Back-chipping was a common occurrence in this study of these fractures, observed in 87.5% of annealed glass samples and 86% of tempered glass samples. However, the thickness of the back-chipping ring on the entrance side is significantly thinner than the bevel on the exit

side. The presence of a millimeter scale can resolve confusion issues by allowing a relative measurement of the back-chipping against the beveled region thickness. After setting up the equipment to take SRP images, the light source should be positioned such that a full, undisrupted image of the light source can be obtained. This may require positioning the light source a few inches off to the side of the fracture to make sure that the entire light source image is captured. Because the SRP images are designed to show a partial light source image, it is crucial to have an image with the full size and shape of the light source for comparison purposes.

There are conditions where glass treatments may interfere with the Hertzian fracture mold formation or the SRP method, making data interpretation difficult or impossible. Coated glass products, such as window tinting or security films, may interfere with the fracturing process. If the exit surface of the fracture is on the nonpolymer side, there should not be interference. If the exit of the perforation is on the polymer-coated side of the glass, the flakes from the fracture may not eject from the glass, instead remaining trapped between the pane and the film. However, the polymer film may distort, leaving a bulge with crushed glass beneath it, such as in Figure 5, which is still detectable by the SRP method. Some surface glass treatments, such as etching, sandblasting, and some polymer coatings, interfere with the reflectivity of the glass surface. The diffuse reflections caused by these materials can prevent high-quality specular reflections of the light source by scattering the light in all directions. Diffuse reflections of the light source are difficult to photograph and characterize, having poor light intensity and no distinct, regular shape. Molded glass surfaces, including rolled glass (colored or colorless), stained glass, or molded glass objects, may not respond well to the SRP method. Many molded glass products have uneven surface textures and flatness, in either regular or irregular patterns. Because the surface flatness is affected, the reflected image may be distorted or disrupted beyond interpretation. In cases where the surface reflectivity is in question, the photographer should attempt to collect a calibration image on a similar object before proceeding.

Conclusions

The SRP method has currently been tested only for orthogonal bullet perforations. A more extensive study of nonorthogonal impact angles and nonpenetrating impacts, as well as validation studies, are part of the next testing phase. Additionally, a wider variety of glass characteristics in the form of thicknesses, coatings, and objects needs to be investigated, as well as other glasslike materials with similar fracturing behavior, such as acrylic and polycarbonate. Despite additional testing still to be done, the theoretical basis of the SRP method is sound. Deviations from the data shown here would likely be caused by inconsistencies or additions in the fracturing process, some of which have been discussed previously, or issues with the surface reflectivity.

Determining which side is beveled in a Hertzian fracture from standard glass fracture documentation images is unreliable because the analyst attempts to guess from which glass surface bright elements highlighted in the damaged area originated, leading to potential misinterpretation. The advantage of the SRP method is that by measuring the smooth, flat surface structure of undisturbed areas around the Hertzian fracture with a light source reflection, the damaged areas are easily detected. This leads to a more accurate interpretation of the impact directionality and provides secondary documentation of the evidence analysis. The SRP method is simple and rapid; setup and imaging takes minutes, generally without a significant investment in additional photographic equipment. Although it is ideal for the shooting reconstructionist to observe the evidence first-hand, with collection of the surface contour in the SRP data, the expert need not be present, nor does the fragile glass evidence need to be preserved and transported, for a proper analysis or verification to occur.

Acknowledgments

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References

1. McJunkins, S. P; Thornton, J. I. Glass Fracture Analysis. A Review. *For. Sci.* **1973**, *2*, 1–27.
2. Thornton, J. I. Interpretation of Physical Aspects of Glass Evidence. In *Forensic Examination of Glass and Paint: Analysis and Interpretation*, 1st ed.; Caddy, B., Ed.; CRC Press: London, U.K., 2001; pp 97–122.
3. Scientifc Working Group for Materials Analysis, Glass Fractures. *For. Sci. Comm.* **2005**, *7* (1).
4. Thornton, J.; Cashman, P. Glass Fracture Mechanism-A Rethinking. *J. For. Sci.* **1986**, *31* (3), 818–824.
5. Hopkinson, B. A Method of Measuring the Pressure Produced in the Detonation of High Explosives or by the Impact of Bullets. *Phil. Trans. Royal Soc. London. Series A* **1914**, *213* (497–508), 437–456.
6. Saferstein, R. *Forensic Science: From the Crime Scene to the Crime Lab*, 3rd ed.; Pearson: Boston, MA, 2015; pp 357–361.
7. Koons, R. D.; Buscaglia, J.; Bottrell, M.; Miller, E. T. Forensic Glass Comparisons. In *Forensic Science Handbook*, 2nd ed.; Saferstein, R., Ed.; Prentice Hall: Upper Saddle River, NJ, 2002; Vol. 1, pp 161–214.
8. Haag, M. G.; Haag, L. C. Projectiles and Glass. In *Shooting Incident Reconstruction*, 2nd ed.; Academic Press: San Diego, CA, 2011; pp 125–142.
9. Byous, J. *Hertzian Fractures and Related Terms–A Glossary.* AATR Publishing, Savannah, GA. 2013. http://www.dowdresearch.org/Hertzian_Cone_Glossary.pdf (accessed July 17, 2018).
10. Young, T. R. Appendix: Darkfield Illumination. In *Crime Scene Photography*, 3rd ed.; Robinson, E. M., Ed.; Academic Press: San Diego, CA, 2016; pp 744–745.
11. Witzke, D. Digital Imaging Technologies. In *Crime Scene Photography*, 3rd ed.; Robinson, E. M., Ed.; Academic Press: San Diego, CA, 2016; pp 587–625.
12. Ingle, J. D.; Crouch, S. R. *Spectrochemical Analysis*, 1st ed; Prentice Hall: New Jersey, 1988; p 33.