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A systemic review on ricochet gunshot injuries

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ABSTRACT

Ricocheted bullets may still retain sufficient kinetic energy to cause gunshot injuries. Accordingly, this paper reviews the literature surrounding gunshot injuries caused by ricocheted bullets. In doing so, it discusses the characteristics of ricochet entrance wounds and wound tracks, noting several important considerations for assessment of a possible ricochet incident. The shapes of ricochet entrance wounds vary, ranging from round holes to elliptical, large and irregular shapes. Pseudo-stippling or pseudo-gunpowder tattooing, pseudo-soot blackening and tumbling abrasions seen on the skin surrounding the bullet hole are particularly associated with ricochet incidents. Ricocheted bullets have a reduced capability for tissue penetration. Most of the resulting wound tracks are short, of large diameter and irregular—all artefacts of the instability of a bullet that has ricocheted. A ricocheted hollow-point bullet, in particular, may over-penetrate the tissue when the bullet nose is deformed or fails to enter the body in a nose-forward orientation. Similarly, internal ricochet may occur when a bullet strikes hard tissue. Postmortem computed tomographic imaging is useful for localising a bullet and its fragments in the body and characterising the wound track. Ricochet cannot be ruled out in normal-appearing entrance wounds unless that finding is supported by other evidence, including the geometrical constraints of the shooting scene and the absence of ricochet marks and a ricocheted bullet.

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1. Introduction

Projectile ricochet is defined as "the continued flight of a rebounded projectile and/or major projectile fragments after a low-angle impact with a surface or object" [1]. Ricocheted bullets may still be able to cause injuries even after having suffered some loss in velocity. Unintentional injuries and deaths resulting from ricocheted bullets have been reported occasionally, and sometimes the manner of death in such incidents is controversial [2–4]. The *Handbook of Forensic Pathology*, published by the College of American Pathologists (2003) [5], stated that "death of one who is struck by a ricochet from a firearm fired legally may be classified as accident". However, if death caused by a ricocheted bullet that the discharge was a volitional act or there was an evident intention to threaten or harm somebody with a gun can be judged as voluntarily killing. Even so, humanitarian issues arise from these undesired firearm injuries [2,6–9].

The interpretation of ricochet gunshot injuries can pose a challenge for many forensic pathologists. Any factors, whether bullet entry location or direction or the underlying bony structures, that cause the entrance wound to have an atypical appearance thereby complicate interpretation of the injury. To establish the facticity of a ricochet shooting incident, knowledge about the process of bullet ricochet and a ricocheted bullet's attendant wounding effect is very important. Gonzales (1934) [10], who examined rectangular gunshot entrance wounds caused by ricochet, was among the first to study ricochet gunshot injuries. Since 1960s, however, research on ricochet gunshot injuries has been conducted by many forensic practitioners and scientists, including Donoghue, Haag, Haag, DiMaio, Hawley, Schyma and Placidi, Gunsentsov, and Hlavaty [1,2,11–17].

This paper reviews the literature surrounding ricochet gunshot injuries with an eye to helping forensic pathologists better understand this issue while serving as a useful reference for interpretation of ricochet gunshot wounds. It discusses the characteristics of entrance wounds and wound tracks such as are caused by ricocheted bullets, examining several factors worthy of consideration during the investigation of a possible ricochet incident.

2. Materials and methods

PubMed, Scopus, SpringerLink, ScienceDirect, AFTE, and university library databases were used as resources for a literature search that centred on the keywords "ricochet gunshot injuries", "postmortem imaging" AND "gunshot injuries", "trace evidence analysis" AND "ricocheted bullet", and "bullet ricochet". These searches returned 1502 English-language articles published from January 1900 to January 2017 (in forensic discipline). After excluding overlapping results and numerous other unrelated articles (e.g., articles discussing ricochets caused by nail guns), 112 publications remained for review.

3. Ricochet gunshot injuries

Ricocheted projectiles may retain sufficient energy to cause severe or even fatal injury even after having been decelerated, deformed or fragmented [6,9,12]. The extent and nature of such injuries depend on the physical characteristics of both the projectile and the tissues it encounters—for the former, constitution, shape, mass, velocity, and orientation; for the latter, tissue density, strength, elasticity, and anatomic relationships [18–22]. The overall extent of tissue destruction caused by a penetrating projectile is determined by missile-tissue interaction [23,24].

3.1. Entrance wound

3.1.1. Morphology

Most commonly, ricochet entrance wounds are described as being atypical: large, irregular, elliptical or keyhole or D-shaped, having ragged edges and wide, eccentric, abraded margins. Some have a large stellate appearance [6,13,15,16,25–27]. Ricocheted bullets, being destabilised, yaw and tumble in their postimpact flight. They may strike the body in any orientation, causing entrance wounds whose appearances range from typical round to large and irregular [1,15,27–30]. When Haag (2007) [12] used six cardstock witness panels (at spacings of 15 cm) to explore bullets' post-ricochet behaviour, one of the tested bullets produced a round hole in the third witness panel but fully yawed on striking the fifth witness panel.

In a case reported by Spitz (1969) [3], a ricochet entrance wound produced by a 9 mm Luger initially went unrecognised because it resembled a close-range entrance wound—this despite the lack of gunpowder and soot deposits around the bullet hole. Even though the accused denied having fired at the victim—but rather claimed to have fired in a different direction—he was convicted of murder. Suspicion of ricochet later arose in response to questions remarking on the absence of gunpowder and soot deposit in the surrounding skin of the bullet hole. When evidence from test firings finally explained the appearance of this gunshot injury by supporting the conclusion that it had been caused by a ricochet rather than a close-range shot, the trial was reopened and the case dismissed. Ricochet thus cannot be ruled out even in cases featuring a round entrance wound.

Gusentsov (2014) [17] further examined the influence of angle of incidence on the morphology of ricochet entrance wounds, performing test shootings at incident angles of 10°, 20°, 30°, 40°, and 50°. Among four groups tested, 44% of entrance wounds were nearly round, 24% were polygonal, 21% resembled English letters (e.g., C, F, G, L), and 11% resembled a slit. Ricocheted bullets tended to create nearly round entrance wounds at low incident angles, but variance in appearance of entrance wounds increased with angle of incidence.

At an incident angle of 10°, Hlavaty et al. (2016) [11] investigated the roles of bullet calibres, bullet types, and impact surfaces on the morphology of ricochet gunshot injuries. The most commonly used handgun calibres—0.22 Long Rifle, 9 × 19 Parabellum, 0.40 Smith & Wesson, and 0.45 Automatic Colt Pistol (ACP) handgun ammunition and 5.56 mm and 7.62 mm rifle ammunition—were selected for the study. Four types of ammunition were used—solid, total metal jacket (TMJ), hollow-point (HP), and full metal jacket (FMJ)—against five targets surfaces: concrete, clay brick, asphalt, aluminium sign, and flat paint-coated drywall (in all experimental cases, ricochet did not occur in bullets encountering drywall at a 10° angle of incidence and above). All examined entrance injuries had at least one atypical characteristic, whether size/shape irregularity, pseudo-stippling, exit wound mimicking, or lack of abraded margins, and no remarkable difference distinguished among wounds from different calibres or bullet types. By contrast, all direct-fire entrance injuries displayed a typical round appearance exhibiting marginal abrasions and having a diameter smaller than that of the bullet producing it. Among the five impact surfaces tested, asphalt ricochets were found to produce the greatest variety of entrance wound appearances—likely owing to the heterogeneous composition of asphalt.

3.1.2. Pseudo-stippling

When the victim is close to the impact site, transference of intermediate surface materials and fragmented projectiles may cause satellite injuries around the bullet hole, manifest as numerous punctate abrasions to the skin [2,6,12,15,16,27,31]. These satellite injuries are also known as pseudo-stippling or pseudo-powder tattooing, for they resemble gunpowder tattooing such as that caused by a close-range shooting [6,27,28]. Pseudo-stippling or tattooing marks can be distinguished from true gunpowder tattooing by their wide range of injury sizes and uneven distribution. The particles of intermediary objects and projectile fragments tend to be larger and more irregular and are more sparsely distributed than those derived from propellant. Multiple shot channels around the main wound track produced by small pieces of debris originating from a fragmented bullet have been reported [12,15,16,27]. Notably, pseudo-stippling marks can be absent from an entrance wound that is covered by clothing.

A variety of pseudo-stippling effects are seen among ricochet targets having different properties. Unyielding and nonfrangible materials (e.g., concrete, marble, steel) do not usually produce noticeable pseudo-stippling marks on the surrounding skin of the bullet hole. Yielding but nonfrangible materials (e.g., aluminium signs) may cause a small amount of satellite injuries. Frangible materials, such as clay brick, fragment on impact and produce various pseudo-stippling patterns. Asphalt, though of dual composition (unyielding mineral and yielding organic materials), creates pseudo-stippling marks similar to those associated with frangible materials. Notably, asphalt pseudo-stippling marks mimic true gunpowder stippling by their similarity to its black dust. Comparison of pseudo-stippling marks created by different bullets reveals that those created by rifle-firing bullets are more significant than those created by handgun-fired bullets [11].

However, ricochet is not the only situation that can cause pseudo-stippling. Bullet perforation of an intermediary object (such as glass), bullet fragmentation, antemortem or postmortem injuries and many other artefacts can mimic gunpowder stippling [16,27,31,32]. Techniques for further analytical and qualitative investigations include neutron activation analysis (NAA), atomic absorption spectrophotometry (AAS), inductively coupled plasma mass spectroscopy (ICP-MS), scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM/EDX), and atomic force microscopy (AFM) [1,33].

3.1.3. Bullet wipe

When a bullet enters the body, its surface lubricant, debris, and bullet traces may be deposited around the edges of the bullet hole, displaying a dark well-demarcated ring known as bullet wipe. This can be seen in skin or clothing in the immediate vicinity of the bullet hole [17]. Rifle bullets do not leave bullet wipe as frequently as handgun bullets do, and the bullet wipe caused by TMJ bullets is generally more apparent than that caused by HP bullets [11]. Ricochet bullet holes have less significant bullet wipe than those caused by a direct shooting owing to having lost some bullets' surface contaminants while ricocheting [1,2,11].

3.1.4. Tumbling abrasions

Hawley et al. (1987) [14] described tumbling abrasions as "atypical gunshot entrance wounds that demonstrate remote, spatially separated abrasions that resemble 'slap' wounds". Such abrasions are caused by the same ricocheted bullet as produced the associated bullet hole on the body. When the tumbling ricocheted bullet approaches the body tangentially, it strikes and skips across the skin before entering it, producing linear abrasions close to the entrance wound. The entrance wound often has an elliptical appearance, with contusion appearing near the bullet hole itself. Such injuries may mimic the injuries caused by blunt force. Recognition of these abrasions' pattern and their relation to the gunshot wound can help determine the shooting direction.

3.1.5. Pseudo-soot blackening

When a bullet ricochets off asphalt, the transferred fine asphalt materials may stain the skin surrounding the bullet hole in such a way as to mimic the soot effect seen in a close-range gunshot wound, thereby producing what is called pseudo-soot blackening [27,28,32,34]. This may also be caused by a disintegrated lead-core bullet subsequent to ricochet, in which case a black ring around the periphery of the entrance wound is produced by the lead deposit [27].

3.2. Wound track

A projectile's behaviour in the tissue is affected by the resistance of the medium along the line of the projectile's trajectory. A bullet will deflect or rotate when travelling in tissues that has high or inhomogeneous density [24]. When a bullet enters the body pursuant to a direct-fire shooting, tissue resistance changes bullet's nose-forward flight by increasing the angle between the trajectory and the bullet's long axis. This angle increases gradually during the whole yawing motion until it reaches 180° at which point the bullet base becomes the leading part in flight. The bullet travels in the base-forward position, this being more stable than the alternative. Bullet deceleration is enhanced by the increases cross-sectional area presented during the process, and as the bullet's kinetic energy depletes, the penetration ultimately terminate [1,12,22,24]. Short or nearly round pistol bullets tend to produce straight wound tracks in tissue, whereas elongated bullets, such as the vast majority of rifle bullets, tend to create spindle-shaped wound tracks that can typically be divided into three different sections: a narrow channel, an enlarged cavity, and a tail end [12,24].

The wound tracks created by ricocheted bullets are often described as being shorter, larger in diameter, and more irregular in shape than the wound tracks that result from direct shooting [2,6,7,12]. In one study, Schyma and Placidi (1997) [2] tested 9 mm Luger hollow-point Action Safety ammunition and found that Action-1 and Action-3 bullets showed a 10–20% reduction in penetration after ricochet. Haag (2007) [12], moreover, explained the likely causes for such decreased penetration of ricocheted bullets by comparing the wound tracks resulting from directly shot bullets with those produced by ricocheted bullets. To minimise velocity loss in tested bullets, the angle of incidence for ricochet was designed to be low, the pre- and post-ricochet distance short. Directly shot bullets penetrated deep to the end of the tissue-simulant block, leaving a relatively straight and small-diameter wound track, whereas the ricocheted bullets penetrated approximately two thirds of the length of tissue-simulant block, leaving a larger-diameter wound track. Haag attributed the decreased penetration of ricocheted bullets to their instability instead of their reduced impact velocity, noting that their velocity loss was small. Compared to directly fired bullets, which can, maintain nose-forward penetration for some distance before yawing in the tissue, ricocheted bullets may enter the tissue in an already yaw condition, causing them to decelerate more rapidly still while producing shorter wound paths than those from direct fire.

In another study, wound tracks produced by three directly shot lead round nose (LRN) bullets having different impact velocities (396, 390, and 288 m/s) were examined. The bullet having the greatest impact velocity did not produce the longest wound path—the result of expansion and yawing in tissue simulant [1]. Hence a bullet's the capacity for tissue penetration is determined not by the impact velocity but rather its stability in the tissue.

Because of their unstable nature, ricocheted bullets tend to produce penetrating rather than perforating wounds [1,6] Indeed, Pippal et al. (2009) [35] reported a rare case in which a 14-year-old boy was struck on the face by a ricocheted bullet yet remained able to walk into the emergency department. The bullet had entered from his right temporozygomatic region and tangentially penetrated the soft tissue and the parotid gland but had not damaged the facial nerve. After passing through the angle of mandible posteriorly, it had stopped and buried itself in the sternocleidomastoid muscle, just lateral to two important vessels: the internal carotid artery and the internal jugular vein. The entrance wound was 3×1 cm and elliptical, without remarkable deposit on the skin surrounding the bullet hole. The bullet was successfully removed, and the boy recovered without any functional impairment.

Increasing attention has been given to the paradoxical penetration behaviour exhibited by ricocheted hollow-point bullets. To decrease the risk of overpenetration, hollow-point bullets are designed to expand (or mushroom) when entering the body and so to quickly decelerate. When a ricocheted hollow-point bullet does not strike the tissue in the nose-forward orientation, however, it may fail to expand [1,2,36]. Schyma and Placidi (1997) [2] report that none of 12 tested ricocheted Action-1 and Action-3 bullets (9 mm Luger hollow-point Action Safety Ammunition) expanded when penetrating a tissue simulant, in every case as a result of nose deformation; two of them produced wound tracks longer than those created by control shot. In view of a fatal ricochet case presented, two scientists questioned the degree of safety achieved by this particular ammunition.

Conventional X-ray examination and computed tomography (CT) examination are commonly used for postmortem assessment of the wound track. Three-dimensional CT imaging allows more accurate wound track characterization and bullet (and fragment) localization than does two-dimensional X-ray imaging. Cone-beam CT and multiphase postmortem computed tomography angiography (MPMCTA) can effectively reduce artefacts caused by metal that seen in the widely used multi-slice CT imaging. Postmortem magnetic resonance (PMMR) imaging depicts soft-tissue damage in higher resolutions but is contraindicated when a ferromagnetic bullet is present in the body lest the bullet migrate during scanning process. However, postmortem imaging assessment of gunshot injuries is merely an adjunct to autopsy: Forensic autopsy remains the gold standard [16,27,28,37–85].

3.3. Internal ricochet

Ricochet may occur inside the body when the bullet strikes hard tissue.

Intracranial ricochets fall into three types: (1) After ricocheting off the inner table of the skull, the bullet re-enters the brain and produces another wound path. (2) When the bullet enters the skull obliquely, it may travel a curved course along the inner table of the skull after ricocheting off it, producing a gutter-like wound path on the surface of the brain. (3) The bullet exits through its entrance wound after ricocheting off the inner table of the skull [34,86–90].

A bullet may also ricochet off the vertebral body to produce a wound path in the spinal canal that is not in line with the shooting direction. The immediately resulting wound path is distinguished from spontaneous migration of a bullet in the spinal canal such as can be caused by gravity, coughing, movement of gastrointestinal tract, and blood flow [91,92].

A case of intraocular ricochet of a shotgun pellet has been reported by Bersudsky et al. (2000) [93] in which the right eye of a man was injured by a pellet from an accidently fired No.6 birdshot. The pellet entered the eye by perforating the inferior edge of cornea and iris root. After travelling through the vitreous, it ricocheted off the macular area, re-entering the vitreous cavity and eventually embedded in the superior edge of the lens.

4. Other considerations in ricochet incident evaluation

Evaluating a possible incident of ricochet shooting is a multidisciplinary effort. Apart from forensic pathological evaluation, crime scene investigators, ballistics analysts, and firearm examiners are often involved. As a growing body of research regarding projectile ricochet is published, investigation of such incident is no longer intractable.

4.1. Crime scene

Because bullet ricochets follow the laws of physics, ricochet can be judged unlikely if certain conditions are not met. The distance between victim and shooter must be sufficient for a ricochet to have taken place, and the angle of incidence must not exceed the critical angle—which can be estimated after identification of the impact surface. The nature of the impact surface influences the resulting ricochet angle, which is commonly lower than the corresponding incident angle when involving hard impact surfaces but higher when involving relatively soft impact surfaces. Finally, the location of the entrance wound must be at a commensurate level in the body [1,6,12,94].

Ricochet marks—damage to intermediate objects produced by a ricocheting bullet—are invaluable evidence in a crime scene. Several ricochet marks, including pinch point, lead-in mark, tunnel ricochet mark, boat wave fractures, and lead splash, can provide great insight into both angle of incidence and direction of bullet path [1,94–101].

4.2. Ricocheted projectile

A ricocheted bullet's capacity for producing a gunshot wound depends on its postimpact mass, velocity, and shape [18–20,27,28,30,102,103]. An estimated minimum of 61 m/s (200 fps) post-ricochet velocity is required to perforate the human skin and penetrate the underlying tissues [1]. (Notably, an energy level of 1000 J may be associated with remarkable tissue injury [104].)

The ballistics coefficient (BC) was introduced as an indicator of a bullet's ability to overcome air resistance in flight—that is, of its capacity to retain its initial speed. A greater BC value indicates that a bullet suffers little deceleration in flight. The BC values of many ricocheted bullets have been examined (in a number of intermediate objects using a range of bullet types at various incident angles) using a Doppler radar system at the U.S. Army's Yuma Proving Grounds, the results of which are available in database form [12]. The steeper the angle of incidence, the lower the BC values—and this figure becomes very low indeed when the bullet undergoes deformation or fragmentation. To investigate a bullet's ability to produce ricochet injuries, its postimpact velocity can thus be calculated by its BC—which may also provide an estimate of the maximum range of the bullet after ricochet. If the calculation indicates that postimpact velocity would be far less than that required to cause a gunshot wound, ricochet injury can be ruled out [12].

In most cases of ricochet, the bullet can be recovered from the victim's body [28]. If the bullet is not severely deformed or fragmented, typical damages sustained during ricochet can be seen. These may aid determination of the angle of incidence, the impact velocity, and the mechanical properties of the intermediate target. For example, when a bullet ricochets from a hard surface (e.g., concrete, glass, steel, marble), it sustains flattening on the side of contact. This flattened surface will be striated if the intermediate target is rough, polished if the intermediate target is smooth. By measuring the angle between the flattening plane and the bullet's longitudinal axis, the angle of incidence can be estimated

[1,6,95,96,105]. Relatively soft impact surfaces, such as gypsum fibreboard, greenboard, and medium-density fibreboard, have a "wipe clean" effect on the ricocheted bullet whereby contaminants (e.g., lubricant, gunpowder, soot) on the side of contact are wiped off, producing a shiny appearance on the bullet's side of contact [96].

Mutual transfer of trace evidence may occur between the bullet and the ricochet target in which impact surface materials adhere to the bullet and the bullet leaves traces on the impact surface [1,6,8,12,100,106]. Even the weave pattern of clothing may be embossed on the surface of the bullet [6]. Such traces can be collected and analysed using SEM/EDX or other such techniques—for example, thin-layer chromatography (TLC), high-performance liquid chromatography (HPLC), polarised light microscopy, and instrumental neutron activation analysis (INAA)—as befits the characteristics of the traces in question [6,12,96,106–112]. Haag (2007) [12] notes that particles adhering to the ricocheted bullet cannot be easily removed during wounding or even during the subsequent handling process. Water, however, is a special ricochet target: In such an instance, retrieval of trace evidence may be difficult.

Molina et al. (2012) [30] reported one case in which an atypical gunshot entrance injury first deemed the product of a ricochet was later rediagnosed owing to a lack of persuasive ricochet characteristics on the bullet. The gunshot entrance wound was rectangular and had no pseudo-stippling marks, the wound track in the head was short and a flattened bullet was recovered—all of which supported a finding of ricochet. But further investigation found no typical polished or striated appearance on the flattened surface of the bullet, nor any other damage indicating that the bullet had undergone a ricochet. Moreover, investigators were unable to identify a ricochet target at the scene. Test firing performed using the recovered pistol revealed a tumbling bullet flight that could cause atypical gunshot injuries; additionally, the rifle markings on the bullet were very faint. Firearm analysis attributed these to barrel erosion resulting from long use, not to ricochet.

5. Conclusions

Investigation of a possible incident of ricochet requires collaboration on the part of forensic pathologists, crime scene investigators, ballistics analysts, and firearm examiners. Certain characteristics of an entrance wounds can help forensic pathologists identify it as being associated with a ricochet event: Unlike typical gunshot wounds, the shape of ricochet entrance wound can range from round to elliptical, large or even irregular, with ragged, abraded margins. Pseudo-stippling or pseudo-gunpowder tattooing around the bullet hole may be seen when the victim is near the ricochet target. Tumbling abrasions, similarly, are produced when the ricocheted bullet tumbles tangentially across the skin before enter the body. Bullet wipe in the case of a ricochet entrance wound is less significant seen in association with a direct shooting. Pseudo-soot deposit around the entrance wound can be seen in the case of a ricochet off asphalt and on disintegration of a lead-core bullet after ricochet. Ricochet wound tracks are commonly shorter and wider than those that result from a direct shooting. Any condition that prevents hollow-point bullets from expanding in tissue, such as deformation of the bullet nose or entry of the bullet into the body when its nose is not facing forward, increases the risk of overpenetration. However, a bullet may ricochet inside the body by striking bone. Postmortem imaging, especially CT imaging, is useful for characterising the wound track and the penetrating bullet (and/or its fragments). Yet ricochet cannot be ruled out in gunshot injuries having a typical appearance; various investigative findings can all suggest the possibility that a ricochet occurred, including the presence of ricochet marks and the ricocheted bullet.

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