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The Effects of Intermediate Targets on Bullet Trajectory

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I. Background:

Ballistics is the branch of mechanics concerned with the science of the motion, behaviour, and effects of projectiles, including bullets, pellets and missiles. Within forensic science, forensic ballistics specializes in the examination of firearms, ammunition, and associated evidence collected from crime scenes. Depending on the distinct phase of flight of the projectile, this discipline is subdivided into multiple fields: Internal Ballistics, External Ballistics, and Terminal Ballistics.

All the physical and chemical processes pertaining to the events occurring inside the firearm from the instant the trigger is actuated to the moment the projectile exits the barrel is examined in internal ballistics. This branch is the foundation for development of ammunition and firearms. The intricate interactions between the propellant, high-pressure gases, and the projectile are examined. It plays a critical role in improving the performance of the firearm, safety assurance, and prediction of performance of the firearm. The conversion of chemical energy of propellant to kinetic energy involves a series of events that occur during the milliseconds between trigger activation and muzzle exit: Ignition of primer, combustion of propellant, generation of high-pressure gases, and projectile propelling out of the barrel (Ongaro et al., 2024).

Transitional ballistics includes the processes that occur in between internal and external ballistics, i.e. from the moment the bullets exits the firearm till it reaches the target. It deals with how bullet trajectory and stability of the projectile are affected due to the interactions between the escaping gases and the projectile. This sudden release of gases causes a phenomenon called muzzle blast, a shockwave that is caused during shooting, which proceeds to oscillate the projectile.

External ballistics studies the factors that affect the motion of the projectile once it has left the barrel and enters the air or space. The bullet's trajectory and range is predicted by taking into account factors like gravity and air resistance (drag). These cause the projectile to fall, creating the curved trajectory. Apart from this, there are various environmental factors, like wind, that also affect the path of the projectile. Understanding this is essential in military and sporting contexts for accurate targeting (Volgas et al., 2005).

Terminal ballistics is the branch that deals with the effects caused by the impact of a bullet on the target upon hitting it. It includes understanding characteristics such as penetration through the target, deformation of the bullet, and transfer of energy between the two. This can also be called Wound Ballistics in cases when the target is any living being and a wound is caused on the target (Nandi et al., 2022, pp. 6–7).

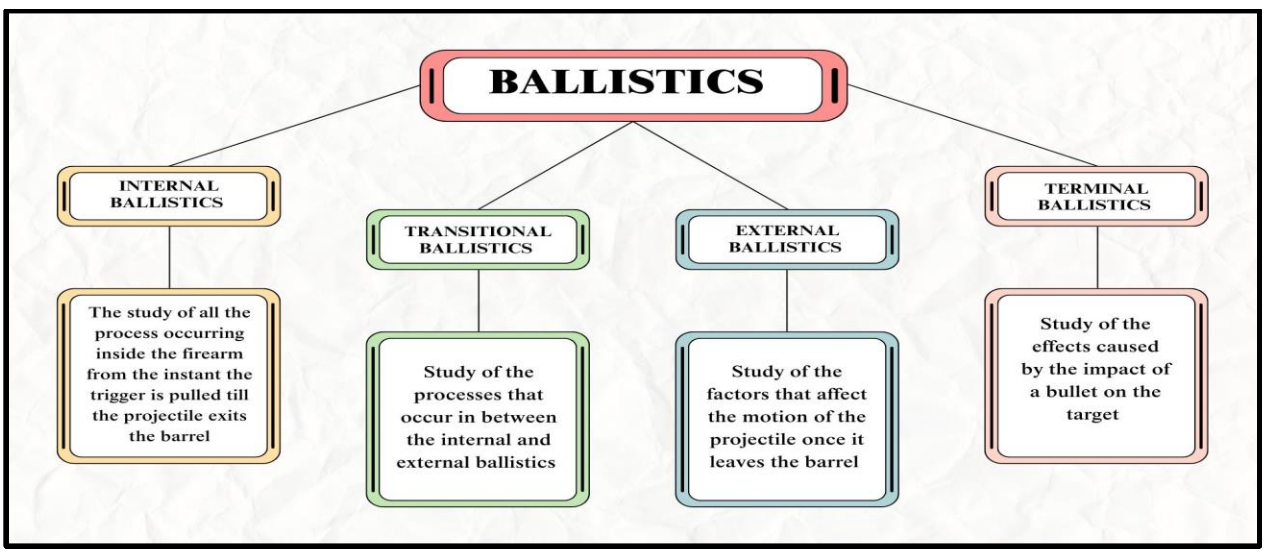

Fig. 1.1 Flowchart depicting the different branches of ballistics

Bullet trajectory: During any shooting incident, it is very crucial to determine the sequence of events that led to the incident, and the determination of the trajectory of the bullets is fundamental for this purpose. Bullet trajectory is defined as the path it takes from the muzzle of the firearm to the final target position. From this, we can infer details regarding the source of shooting; this includes the position of the shooter, firing angle, and ricochet effects. Determination of bullet trajectory is done by studying certain indicators like the presence of any secondary bullet holes, burns caused due to GSR (Gunshot Residue), ricochet marks etc.

According to the study done by Mitosinka and Contra Costa County Sheriff's Dept. (n.d.), bullet trajectories can be determined by analysis of paint fracture patterns on malleable or painted surfaces like automobile bodies. When the bullet travels parallel to the impacted surface there is absence of certain trajectory indicators, such as bullet holes and ricochet markings. Deformation of metal surfaces due to the bullet causes the brittle paint layers to fracture in various parents. Fractures are observed in the form of wave-like lines, protruding outwards from the point of impact and aligning in the direction the bullet travels. On applying black fingerprint powder to the fracture lines and lifting them by using a transparent tape one can examine these patterns under higher magnification.

Intermediate targets: The projectile's path can be greatly changed when it comes across an obstacle during its flight. These obstacles that often come in between the projectile and its final point of impact with any object or the victim are known as intermediate targets. Forensic Ballistics initially dealt with the identification of firearms by analysing striations and biological remnants found on the bullets. The underutilised field of the study of intermediate targets being embedded on the bullets shows promising results in the study of reconstructing projectile trajectory. These trace evidences hold high evidentiary value and help in the determination of sequence of impact, distinguishing between accidental and intentional firing.

The interaction of bullets with intermediate targets such as wood, glass and textiles, facilitates material exchange and deformation of the bullet. The deposition can be found both on the bullet and target material The pattern of deposition is based on the chemical and physical properties of the target, angle of impact and the structural composition of the bullet. Further additional information can be obtained from the analysis of ricochet marks and projectile deformation such as energy dissipation and impact mechanics.

Vermeij et al. (2012) in their research demonstrated that the materials from intermediate targets adhere to bullet particles predominantly around the nose and flattened surfaces and the sequence of events can be observed using the stratification of material layers found on the bullet. Hard materials such as glass made substantial deformation and ricochet marks. These findings highlight the importance of trajectory reconstruction and assessment of ballistic evidence.

Interaction Between Intermediate Target and Bullet

As the bullet interacts with an intermediate target, the trajectory and behaviour are influenced by various physical processes. There are various interactions which are discussed as follows.

Velocity change - When the bullet strikes the intermediate target, some amount of its kinetic energy is absorbed or dissipated by it and this ultimately reduces the bullet's velocity. It is also observed that denser and thicker targets cause greater deceleration due to higher resistance. In addition to this, partial deflection caused by oblique impacts also led to velocity reduction.

Energy transfer - A part of bullets' kinetic energy is transferred to the intermediate target, which results in shattering of the target. This could be due to the conversion of energy into heat and sound during the impact (Kerkhoff et al., 2023).

Bullet deformation and fragmentation - Depending upon the bullet's properties like hardness, ductility, etc, it undergoes deformation. For instance lead core bullets deform more readily than steel core or jacketed bullets. Fragmentation depends on target material and bullet construction and also leads to formation of secondary projectiles. Structural stress is another phenomenon which causes the bullet to deform or fragment. It refers to the force built inside a bullet when it hits a target or experiences an impact. This force can cause it to stretch, compress, bend or break, based on its strength and the force applied (Farrugia et al., 2009).

Impact on trajectory angle and stability - Due to the asymmetric forces the bullet experiences angular deflection. Its degree varies on factors like surface irregularities, angle of yaw and material properties. Gyroscopic motion is the tendency of a rotating object to maintain its orientation. During an impact with an intermediate target the bullet loses its stability due to change in its gyroscopic motion leading to tumbling (Liu et al., 2021).

Main Text:

Types of Intermediate Targets and Their Effects on Bullet Trajectory

Intermediate targets can significantly reduce the effectiveness of the projectile due to its changed trajectory as a result of inducement of yaw and tumbling of projectiles. Yaw is the deviation of a projectile from its central axis or flight path. This results in an upward or downward oscillatory movement. The drag (which is caused due to air resistance) and energy transfer is amplified because when a bullet impacts the target, the yawing phenomenon increases the surface area of the bullet that comes in contact with the target. This is minimised in rifled firearms as the rifling, which imparts spin to the bullet, stabilizes it. When the yaw angle is more acute, the bullet becomes increasingly unstable, transitioning into tumbling behaviour. Tumbling is another phenomenon where the bullet is deviated from its original path but in this the bullet rotates end-over-end upon interacting with the targets. In cases of wound ballistics, tumbling causes irregular wound profiles making the reconstruction of bullet trajectory more complicated. (Humphrey & Kumaratilake, 2016).

Another effect caused by these intermediate targets is known as ricochet. According to Karger (2014), ricochet is defined as the deviation of the bullet from its original path upon coming in contact with an intermediate target. The deviated trajectory after ricochet does not follow the conventional laws of reflection. In this, when the surface on which the projectile strikes is hard and dense, the angle of incidence is greater than the angle of departure. When the target surface is soft and flexible, the angle of departure is greater than the angle of incidence. At very low incident angles, the trajectory of the bullet is majorly deviated from its central

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axis. This phenomenon causes the projectile to get destabilised. This destabilisation of the bullet plays a critical role in bullet trajectory reconstruction cases from gunshot injuries (Nishshanka et al., 2022).

Upon hitting intermediate targets, it is observed that shotgun pellets tend to spread out. This phenomenon is caused by the intervening surfaces between the shotgun and the target. According to the study performed by Karapirli et al. (2014) it was observed that denser intermediate targets (for example flat iron, and aluminium) caused more intense pellet spread than that of the less denser materials (examples include, glass and grey cotton fabric). Thus intermediate targets with high density materials cause greater dispersion of shotgun pellets.

Intermediate targets differ remarkably in their structure and composition. It could be regularly encountered materials like glass, wood, and metal, or some unconventional ones like vegetation or multilayered objects.

In crime scenes, glass is a frequently encountered intermediate target, typically in the form of car windshield or building windows. The physical and mechanical properties of glass, such as density, hardness, refractive index and fracture behaviour, influences its interaction with the projectiles. Fracture behaviour of the glass influences the trajectory of the projectile, i.e. the fractures create non-uniform breakage, affecting the bullet’s path (Waghmare et al., 2003). In cases when the bullet hits a laminated glass, which contains a layer of glass and a layer of polymer, the shattering of glass is prevented as the polymer layer holds the fragments together (Osnes et al., n.d.).

When a bullet in flight interacts with a wooden surface, it often undergoes the ricochet phenomenon and variations in deflection angles. The wooden surface also alters the bullet's rotating patterns. On firing the bullet from different angles, ricochet angles and deflection angles are analysed. Ricochet angles exceeded the angle of incidence and increased gradually. The deflection angles increased with higher angle of incidence due to deeper bullet penetration and greater interaction with the wooden surface. Thus it can be considered that type of wood, its orientation and the bullets rotation have an influence in the deflection angles during ricochet (Mattijssen et al., 2016).

In the paper by Cail and Klatt (2013) they discuss the influence of clothing as an intermediate target. The interaction of shotgun pellets with fabric introduces varying levels of resistances based on fabric composition, weave and thickness. Factors such as pellet size, muzzle velocity and the range of fire influences the shotgun firing, unlike single projectile firearms. Dense materials such as denim or cotton have greater resistance compared to lightweight fabrics like polyester. The increased distance can decrease the velocity due to drag. Material properties of the intermediate target also affect the penetration of pellets.

Glass as An Intermediate Target

Glass is most commonly encountered by law enforcement officials when the shooting incident occurs during situations that are not standard target shooting. Some general consequences that occur when a bullet hits glass include bullet deformation, energy and momentum loss, and bullet deflection. Deformation of a bullet is more significant when soft-nose bullets are impacting the surface. The stability of the bullet, penetration through the final target or the impact on the actual target is negatively affected due to this deformation. For a bullet to penetrate a glass, energy is consumed, and this is greater if the thickness of the glass is increased. So this loss of energy leads to reduced effectiveness on the final target. The overall firing accuracy is affected due to the deflection/deviation of the bullet when it hits a glass surface (Harper & Northwestern University School of Law Scholarly Commons, 1939). The different types of bullets have varying effects on these intermediate targets. For instance, Full metal jacket (FMJ) round nose bullets have a higher capacity to perforate through glass, despite the angle at which it hits the surface. It also has a relatively high velocity remaining after perforation, so it has a tendency to cause collateral damage even after hitting the intermediate glass surface. Expandable bullets are not as effective and accurate especially when the shooting angle is more acute (Rodrigues et al., 2016). Blunt nosed bullets create shock waves that disseminate radially outwards upon hitting the glass surface. This results in formation of distinct fracture patterns, including radial fractures, concentric fractures and cone fractures (Wang et al., 2023). Bullet passing through a glass surface, such as a window pane, is generally deviated from its normal path. Since window panes are more frequently encountered in shooting incidents, this aspect of ricochet should be taken into consideration while investigating such crime scenes (De Kinder et al., 2001).

Fig. 3.1 (A) One-sided flattening of bullets after ricochet off glass (Vermeij et al., 2012)

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Expanding on the understanding of how bullets interact with glass, a study by Kunz et al. (2012) explores the ballistics properties and wounding potential of different ammunitions on the effect of laminated safety glass as an intermediate target. The main 3 parameters based on which this study was conducted are: ammunition types, shooting angles, and stimulants to recreate real-life scenarios. In this study, 17 types of 9-mm ammunition were chosen based on the different weights, designs, velocities and expanding characteristics. These ammunition types were classified into Expandable Projectiles (hollow-point designs) and Non-Expandable Projectiles (full metal jacket designs). This was tested at 2 shooting angles; 30° for understanding oblique impacts, and 90° to understand perpendicular impacts. The measurements of velocity of projectile, pre-impact and post-impact energy, penetration depth, and angular deviations were done using photoelectric barriers and an electric powder scale. Ballistic Gelatin, Ballistic Soap, and Pig Cadavers were the 3 stimulants that were used to replicate human tissue. Laminated glass was used as an intermediate target between these stimulants to check for the effects of behaviour and wounding capacity. This was placed 25 cm in front of the stimulants. Loss of velocity and energy upon hitting the glass, wound characteristics on the stimulants, and deviation of projectile from its original path after hitting the glass were the main parameters that were analysed from the study. There was a more notable energy loss at lower angles (30°) as compared to perpendicular impact. A similar effect was observed in the deviation of the projectile. At lower angles, since the deviation was higher, the effectiveness of the bullet was lowered. Finally, due to the compromised effectiveness, the wounding capacity of the bullet was also less, resulting in very minimal penetration. Although the paper provides a detailed evaluation of the behaviour of 9-mm projectiles in different conditions, one of the main limitations of the paper is that it is limited to just one type of bullet, but in the real world, there are many other calibres of bullets that are encountered, which will have varied effects.

Beyond ballistic performance, the research has also extended to analyze the characteristics of glass fragments produced by various projectiles. The study conducted by Lux et al. (2022), focused on the breakage patterns of the glass, bullet's trajectories, and ability to cause secondary injuries. In this, a 9 x 19 mm pistol with different types of ammunition; Deformation Projectiles and Full Metal Jacketed (FMJ) Projectiles, was used. The shots were fired at the laminated glass placed at a 15° angle. 3 parameters that were observed are the morphology of glass fragments and their fracture pattern, trajectory of the expelled fragments, and their ability to perforate other targets like skin surrogates and ballistic gelatin. Digital calipers and photographic documentation was used to analyse the expelled fragments. As seen in Fig. 2.2 (a) and (b), both the projectiles resulted in round-shaped compounded glass fragments. Glass shards are seen embedded in the polyvinyl butyral (PVB) layer of the laminated glass. The deformation projectile produced a diffuse fracture pattern, while the FMJ projectile produced radial fracture pattern. Along with this, 3D laser scanning was used to calculate impact angles and deviations. MedCalc was the statistical software that was used to analyze all this data. Though this paper provided insights into the behavior of bullets upon penetrating laminated glass, one major limitation is that there were certain factors which are commonly encountered in real-life that were not taken into account. Some of these factors include yaw, shooting angle, and velocity variation due to external conditions like weather. In terms of wound ballistics, it demonstrates the effects of the bullets on soft tissues, but it does not touch upon the aspect of how much force is required to produce lethal effects.

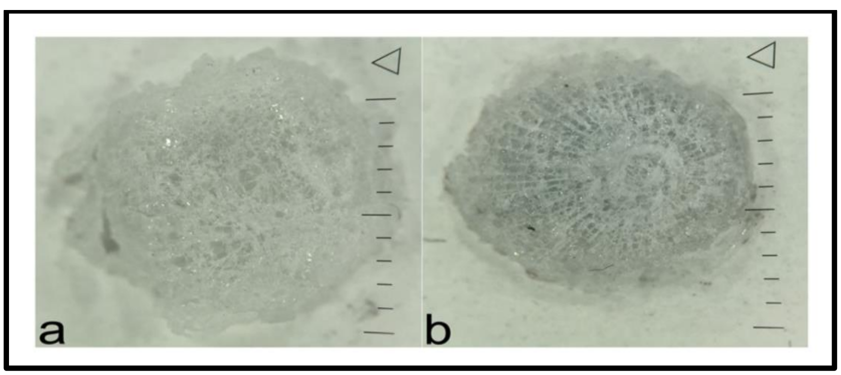

Fig. 3.2 (a) Glass fragment after penetration by deformation projectile. (b) Glass fragment after penetration by FMJ projectile. (Lux et al., 2022)

Wood as An Intermediate Target

Different intermediate targets have different impacts on the bullet's trajectory and its interaction with the target. When a deformed bullet which has interacted with a wooden object/surface strikes a human body it will have a different impact as compared to that of an undeformed bullet. The deformation may reduce the bullet's velocity and the energy it possesses, which decreases its ability to penetrate deeper into the body. When the bullet strikes the wood, it absorbs the kinetic energy of the bullet which ultimately reduces its impact force (Turopoljac et al., 2022). There may be factors which affect the bullet's trajectory upon hitting the wooden surface such as tumbling of bullets, spin or deviation from the original path. These factors result in unpredictable entry angles and wound patterns. In some cases due to loss of energy there will be formation of superficial wounds. Because of the presence of irregular edges and the shape of the bullet it can create extensive tissue damage and irregular wound cavities. Deposition of secondary projectiles such as wood fragments and other debris causes additional injuries and increases the risk of infection. However the impact on the body will vary based on the bullets characteristics, the distance traveled after deformation, nature of intermediate target and the part of the body struck (Koene, 2016).

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VII, July 2025

On the basis of the understanding of how wood acts as an intermediate target and its influence on bullet behaviour, Koene et al. (2017) conducted a study that analysed the penetration and deformation of bullets striking wooden surfaces under varied conditions. In this study, projectiles were fired from laboratory barrels at a distance of 20 meters and the velocities were measured from 5 meters and 18 meters from the barrel. Three types of 9 mm projectiles were used and propellant mass was reduced by 7.5% and 15% to achieve three distinct velocity levels for each projectile. Following this, impact experiments were conducted with flat wooden targets using a high speed camera and the penetration depth was measured using x-ray photographs. The experiment included the following wooden samples:- Douglas, European Pine, European Oak, Merbau, Bangkirai, and Azobe; these targets were stored in a controlled environment at 20°C and 55% relative humidity for three weeks. Depending on penetration depth, one or two wood blocks were used, ensuring close packing when pairs of blocks were necessary. Each velocity/wood combination was tested five times to account for natural variation in penetration depths. Penetration depths were processed using software like DigitizeIt 2.2 and Gwyddion 2.47. Experimental data were analyzed using the Robins-Euler and Poncelet models to estimate material properties. The equilibrium moisture content (EMC) of wood was calculated using Simpson's formula, correlating relative humidity and temperature with wood moisture content. In addition to the results achieved, the paper also consists of certain limitations, some of which include the following aspects. The consistency of the bullet is affected due to the variations in the moisture content in the wood samples. This can be explained in the sample like European Oak, which had a higher moisture content approximately 37.1% , despite having efforts in stabilizing the moisture content. Secondly the factors such as use of flat wooden surfaces could also alter the result output. As we see in real life applications the wooden surfaces are more complex in nature consisting of beams, curved surfaces and layered materials.

Further expanding the scope, Mattijssen et al. (2016) investigated the impact of wood grain on bullet ricochet and deflection, providing critical insights on the material structure and impact dynamics. This was achieved by firing 32 auto bullets at 6 types of wooden boards at different grain angles. Bullets were shot from a submachine gun at a range of 2 meters that impacted the boards at an incidence angle beginning at 10°. For every wood type five shots were fired and the resulting ricochet and deflection angles were measured with the help of a screen, which was placed at 0.5 meters distance from the point of impact. Statistical analysis like Welch's t- tests helped in assessing the bullet rotation on deflection and influence of grain direction. There were certain limitations in this research which could have an impact on the results and its analysis. One such factor involves no examinations done on the effect of the bullet shape, its mass or the different twist directions. All the bullets that were used in the experiments were 4.7g full metal jacket bullets with right hand rotation. Another aspect that acts as a limitation factor is the controlled setup used for conducting the test fire. Test fires were conducted at a distance of 2 meters approximately, whereas in real time applications the distance would vary, causing changes in the final results.

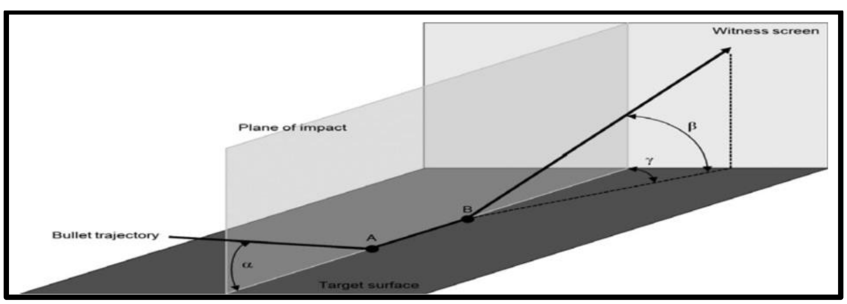

Fig. 3.3 Trajectory of a ricocheting bullet upon impacting the target surface at A and leaving at B. (Mattijssen et al., 2016)

Fabric as An Intermediate Target

Study conducted by Chen et al. (n.d.) discusses how fabric acts as an intermediate material in bullet trajectory and focuses more on the function of fabric as an energy absorbing medium. It can significantly alter the wound characteristics and the bullet's impact on a human body. The predominant factor being the reduction in velocity due to energy dissipation, the more denser the material, the greater they absorb energy such as denim or leather. The dissipation of energy involves several mechanisms such as wave propagation, friction, strain and kinetic energy. The energy is distributed according to the velocity of impact and while at higher velocities energy is distributed in local modes such as Yarn Pull-Out, Fiber/Yarn Rupture and at lower velocities the energy is distributed over a wider area. The difference in fabric structure influences the ballistic performance, The high thread density found in woven fabrics increases their ability to absorb energy and these are found as body armour materials. Unidirectional Fabrics, which are aligned in one direction, can absorb more energy than woven fabrics as they are bonded in matrices. The studies have shown that there is a 30% improvement in ballistic performance for UD fabrics compared to woven fabrics. One of the other factors which can affect the bullet trajectory is the projectile shape and material, projectiles with ogival heads penetrate more efficiently than those with flat heads. Deformation of the bullet can further lead to a combination of reduced penetration, increased tissue damage, irregular wounds and altered trajectory behaviour. Fabric as an intermediate target makes slight adjustments in transferring and absorbing projectile energy, which can affect the bullet trajectory.

In considering fabrics as an intermediate target in bullet trajectory, the study performed by Cail and Klatt (2013) highlights the influence of fabrics on the penetration deviations of shotgun pellets under differing conditions. The methodology used was to determine the effect of common clothing fabrics on the penetration of shotgun pellets at various distances using simulated human

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VII, July 2025

tissue. The materials used for this experiment are a 12-gauge shotgun with a modified choke and No.8 lead shot ammunition. The different targets used were Thin Cowhide to simulate human skin, and Ballistics gelatin blocks to simulate soft tissue. Denim, Sweatshirt, Cotton and Polyester were used as the fabrics. The shotgun was fired at distances of 40, 45, 50 and 55 yards. The targets included gelatin alone, gelatin with skin simulant, and gelatin with skin simulant with different fabric types. The data was collected by analysing the number of pellets that passed through the gelatin, penetrated the gelatin and that hit the target. It was compared across different conditions and distances. Comparisons were made between the targets of gelatin alone, gelatin with skin simulant and gelatin with skin simulant with different fabrics and statistical data was prepared between different fabric types and their respective effectiveness in reducing penetration. Fundamentally beneficial to understanding how fabrics impact shotgun pellet penetration, the research has few limitations. Utilizing ballistic gelatin and cowhide as human soft tissue and skin simulants doesn't quite meet the anatomical diversity and sophistication of real human bodies. Natural elasticity of skin, varying tissue densities, and bone structure can all influence projectile motion in ways that are not feasible for models to replicate. The research also only utilized one kind of ammunition (no. 8 lead shot) and one shotgun model (12 gauge). The findings cannot be universally considered to other guns or other types of ammunition since shotguns allow a tremendous range of shot sizes, shell materials, and choke types. In actual real world situations, the clothing perhaps is not positioned flat and consistently fastened over the skin simulant like done during the test and only four types of clothes were tested: polyester, cotton, denim, and sweatshirts. They did not address materials such as wool, silk, nylon blends, or performance fabrics and their ballistic interactions could be significantly different.

To understand the effect of human skin covered by different fabrics, the experiment conducted by Giraudo et al. (2016) considers various factors such as firing distance, gunshot residue distribution and the combined effect of fabrics. The experimental study analysed firearm wounds on human skin covered by various textiles using materials such as 75 calf sections surgically removed for medical reasons as human skin samples; Fabrics such as Cotton, Jeans, Leather and Nylon; .32 ACP Pistol with full jacketed bullets. The shooting experiment was conducted in a controlled environment and the samples were shot at distances of 5, 15 and 30 cm. Both the entrance and exit wounds were analysed visually and using micro-CT scanning. ANOVA with Bonderroni correction, was used to evaluate the difference between the GSR samples. Radiopaque material which indicates the presence of GSR were assessed in the wounds. Analysis of the distribution of GSR across firing distances and textiles were performed. This methodology helped in the detailed examination of GSR deposition and Wound characteristics of how textiles influence in intermediate gunshot wounds. This study also had few limitations that restricts its generalizability. Surgically removed human limbs lacked muscle tone and blood circulation, important physiological reactions including bruising, bleeding, and skin elasticity were not present in any of the tests. The findings' applicability to live tissue reactions is limited by the postmortem environment. The results cannot be applied to other calibers, bullet types, or expanding projectiles like hollow tips because the study only looked at one type of ammunition - a.32 ACP full-jacketed bullet. Moreover, only one layer of fabric was evaluated in each instance, although in real-world scenario clothing frequently consists of several overlapping layers that may further affect wound characteristics and gunshot residue (GSR) patterns. The study also failed to examine the effects of fabric on wound characteristics at medium or long ranges; instead, it only looked at close-range firing distances (5, 15, and 30 cm).

Fig. 3.4 Arrangement of bullets coated with four different common fabrics (a cotton, b jeans, c leather, d nylon) (Giraudo et al., 2016)

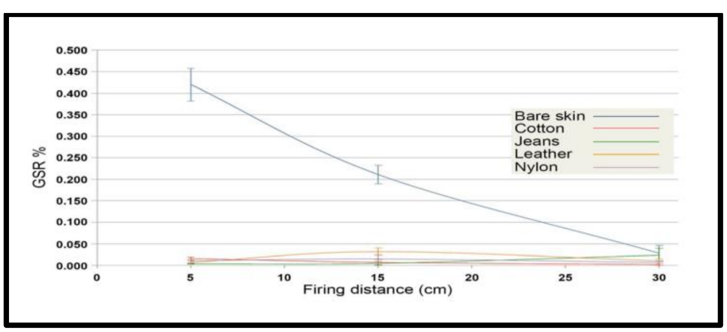

Fig. 3.5 Graph comparing GSR values detected in samples covered by different textiles (cotton, jeans, leather, nylon) and in controls (i.e.. bare skin samples) (Giraudo et al., 2016)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VII, July 2025

Comparative Table of The Effects of Intermediate Targets on Various Bullet Characteristics

As mentioned, various intermediate targets have a wide array of effects on bullet characteristics like bullet velocity, bullet trajectory, deformation of bullet and wounding capacity. These effects differ depending on the physical and chemical composition of the intermediate targets. Real-life incidents where this can be observed include vehicular assaults, murder either in indoor or outdoor shootings etc. Although in real-life scenarios the circumstances are unimaginable, some basic characteristics remain constant.

Intermediate targets like glass, wood and fabrics are taken as an example to understand these effects. The table below summarizes the effects produced by these intermediate targets, giving a concise understanding of how ballistics performance is affected and the resulting wounding implications.

Intermediate Target	Example	Effect on Velocity	Trajectory Alteration	Bullet Deformation/ Fragmentation	Wound Characteristics
Glass	**Windowpane (annealed)**	Moderate to high loss due to shattering	Deflection occurs; angle dependent ricochet	One-sided flattening; cone and radial fractures observed	Reduced penetration; glass shards may cause secondary injuries
	Laminated Safety Glass	High energy absorption (due to polymer layer)	Less shattering; controlled deflection	Flattened nose; stratified material layers	Lower wounding potential; fragments retained by polymer
	Tempered Glass	Very high energy absorption; often complete fragmentation	Chaotic trajectory after fragmentation	High deformation; extensive surface damage	Irregular wounds; glass splinters add to trauma
Wood	**Douglas / European Pine**	Moderate energy absorption	Deflection increases with angle of incidence	Minimal deformation at low velocities; wood grain influences deflection	Superficial wounds; mild tissue disruption
	European Oak / Merbau / Azobe	High resistance, greater deceleration	Ricochet angles exceed incident angle	More bullet distortion; tumbling increases	Irregular, shallow wounds; risk of embedded splinters
	Plywood / Particle Board	Medium resistance; varies by thickness	Greater instability; trajectory unpredictability	Deformation increases at higher impact angles	Entry wound shapes distorted; debris in wound channel
Fabric	**Denim / Cotton**	Moderate energy absorption due to dense weave	Minor effect on trajectory	Slight nose flattening; fabric adherence possible	Reduced penetration; shallow wound; GSR spread affected
	Polyester / Nylon	Low energy absorption	Minimal deflection	Minimal deformation; may cause spinning	Clean entrance; minor energy loss
	Leather / Sweatshirt (thick fabric)	High resistance to penetration	Can cause mild deflection or bullet yaw	Deformation varies; reduced velocity	Entry wounds irregular; less internal injury
	Body Armour	Maximum energy	Can completely stop low-calibre	Significant flattening	No penetration; only blunt force trauma or

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VII, July 2025

	(UD fabric)	absorption	bullets	or arrest of bullet	bruising

Table 4.1 Comparison of different intermediate targets on bullet characteristics – including effect on velocity, trajectory alteration, bullet deformation/fragmentation and wound characteristics.

Applications of Bullet Trajectory Analysis

Trajectory Reconstruction:

The analysis of material traces on the bullet helps the experts to reconstruct the path after the interaction with intermediate materials. The stratified layers of transferred material can be examined to understand the sequence of events, which can be useful involving multiple shooters (Haag, 2020). Apart from the analysis of the physical/trace evidences that are found at the crime, a study done by Teng et al. (2024) initiated a new approach for the detection of trajectory and other information related to the source of gunshot using gunshot acoustics; that is the use of the sounds produced by a firearm to detect the projectile's trajectory, shooter's location etc.

Identification of Intermediate Targets:

The bullet can contain trace materials upon perforation or ricochet, identifying the nature by examining these trace materials can help pinpoint specific locations and aid in reconstruction of trajectory. When the bullet perforates through the surface, traces of the material is seen around the nose of the bullet. This can include the presence of any biological material, like blood or tissue, or any other materials, like concrete or fibers. When a bullet ricochets off of a hard surface, like metal or some types of glass, there will still be presence of microtraces of the material on the bullet along with the deformation of the bullet. In the case of metal surfaces; steel for example; small traces of iron are transferred onto the bullet. There will also be presence of impact holes/marks or some other kind of deformation on the intermediate target's surface, which aids in trajectory reconstruction (Vermeij et al., 2012).

Legal impact in cases:

In cases where self defence or accidental shooting cases are in question, the evidence of bullet trajectory can be examined to show that the shooter may not have intentionally committed the crime. Detailed trajectory analysis can help in establishing the shooter's position and target (Schweitzer et al., 2023).

Damage Assessment:

The deformation of bullets can be studied to understand the patterns formed to deduce the intermediate targets and the angle of impact. By studying the entry wound's geometry (angle of incidence), the approximate position of the shooter can be identified. This analysis must take into account factors like ricochet due to intermediate targets for more accurate identifications (Rodriguez-Pascual et al., 2024).

Conclusion:

To conclude with, forensic ballistics is a branch of forensic science that deals with the behaviour patterns, motion and effects of projectiles and their trajectories, assisting in crime scene investigation and courtroom proceedings. The review paper focuses on the way bullet characteristics, trajectories, deforming patterns and energy transfer are influenced after interaction with intermediate targets such as glass, wood and fabric. Ballistics is a broad field which can further be subdivided into internal ballistics, transitional ballistics, external ballistics and terminal ballistics. Each of these emphasizes aspects of the projectile behaviour from the time of trigger pull till the time of impact. Intermediate targets significantly alter a bullet's trajectory as it leads to reducing its velocity, energy dissipation, deformation and ricochet patterns. The degree of each parameter varies upon different factors such as density of material, its thickness, angle of impact and the type of bullet involved in the trajectory. For instance, a glass surface will cause substantial deflection and deformation of the bullet, whereas a wooden surface will have an impact on the ricochet angles and penetration depth. In addition to this, fabrics act as an energy absorbing medium which alters wound characteristics and bullet paths. These interactions uphold high evidentiary value, because it enables investigators to determine the position of the shooter, firing angle and the sequence of events, as material traces left on the bullets give more detailed information on trajectory reconstruction. The paper focuses on the some different methodologies used for carrying out the examination of impact of bullets and the target.

Although there has been a significant advancement in the field of ballistics, there is a vast scope for further detailed studies. These research gaps involve study of bullet behaviour on a broader range of intermediate targets, different types of bullets, and their wounding capacity. Most studies have been conducted on laminated and tempered glass surfaces, however this can be expanded to various other types of glass, like annealed glass, heat strengthened glass, patterned glass etc. For this purpose, mainly full metal jacket bullets and soft nose bullets were used. Nevertheless, there are multiple other types of bullets that are encountered in ballistics cases, like armor-piercing bullets, wire patched bullets, incendiary bullets etc, that can be further studied for a better understanding of the domain. Moreover, the approach used to analyse wounding potential was limited to ballistic gelatin which is inadequate in mirroring the effects on human tissues, muscles and bones. These research voids provide further scope for systematic analysis and development of new methodologies.

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With the help of these concepts, certain legal cases pertaining to self defence or accidental shootings can be investigated accurately, and damage patterns can be analysed for crime scene reconstruction purposes. This study covers the scientific principles- from what is ballistics to how bullets interact with different surfaces upon impact and its applications in the real world- that make forensic ballistics a key component of forensic science

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