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PAPER

PATHOLOGY/BIOLOGY

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Laminated Safety Glass as an Intermediate Target: A Wound Ballistic Study

ABSTRACT: Various 9-mm ammunitions (A1, A4, A5, ST, GS, GSb, P.E.P., SeCa, HP, PTP/s, VM, McVG, DM41, PTP, SX2, PT, and MEN frangible) were tested regarding their velocity, energy, angle of impact, and potential wound channel after penetrating a car window at 30° and 90°. Test materials were gelatine, soap, and pig cadavers. The velocities of the projectiles were between *c.* 288 and 430 m/ses, the energy spread between 394 and 564 J. Handgun bullets fired through vehicular side window glass lose substantial energy reducing the effectiveness of the ammunition. This effect is greater when fired at an angle of 30° compared to 90°. At a shooting angle of 90°, none of the different projectiles showed remarkable differences considering its wound ballistic features. Accuracy is maintained at a 90° angle but seriously impaired at 30°. None of the examined ammunition complied with the demanded wound channel effectiveness of 30–60 J/cm.

KEYWORDS: forensic science, intermediate target, laminated safety glass, expanding ammunition, nonexpanding ammunition, ammunition effectiveness, wound ballistic study

Specially defined police ammunition has been introduced into the German police force between 2000 and 2007. The reason for this was an insufficient effectiveness of the formerly used projectiles (1). This new type of ammunition fulfills the required technical directive of the police, which implies a low tendency of fragmentation and a wound channel effectiveness of at least 30–60 J/cm over a distance of 5 cm or more (2,3). These requirements are considered to limit collateral damages during a standard police operation. In this context, collateral damage refers to unintended or incidental injuries of innocent bystanders.

To find ammunition, which maintains the required qualities even after penetration of an intermediate target, this research deals with the following questions:

- Which 9-mm ammunition is sufficient to incapacitate a target situated behind a car glass side window?
- Is it possible to gain an immediate physical incapacitation of an encounter with the help of a handheld firearm?
- What kind of wound ballistic effectiveness and precision do projectiles still have after having penetrated a side window of a car?

The main goal of this research is the experimental comparison between different kinds of firearm–projectile combinations regarding their wound ballistic effect and effectiveness after having penetrated a car side window made of safety glass at shooting angles 30° and 90°.

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Materials and Methods

The following 9-mm ammunitions have been used in this study:

Expandable projectiles “Action 1” (A1), “Action 4” (A4), and “Action 5” (A5) by the manufacturer RUAG Ammotec®, the soft point bullet Winchester® “Silvertip” (ST), Remington® “Golden Saber” (GS) and “Golden Saber bonded” (Gsb), the German Metallwerk Elisenhütte GmbH ® “Polizeieinsatzpatrone” (P.E.P.), the Swiss RUAG Ammotec® “Security Cartridge, Safe Environment Controlled Action” (SeCa), HP, and the Metallwerk Elisenhütte GmbH® “Polizei-Trainings-Patrone” (PTP/s).

Nonexpandable projectiles RUAG® “Messing Vollgeschoss” (MsVG) and “Sintox Version 2” (SX2), Dynamit Nobel® “Deutsches Modell der Bundeswehr” (DM41) and the Metallwerk Elisenhütte GmbH® “Polizei-Trainings-Patrone” (PTP).

The ammunitions Metallwerk Elisenhütte GmbH® “MEN frangible” (MEN), the plastic ammunition “Plastik Trainingspatrone” (PT) as well as the 0.45 caliber hollow point projectile Winchester® “Black Talon 0.45 ACP HP” and the 0.45 caliber nonexpandable projectile Winchester® “0.45 ACP VM” (VM) were used for comparable purposes.

In a pilot study, the ballistic behavior of various ammunitions was studied and the most suitable projectiles were selected for further experiments.

The ammunitions were shot from a fixed barrel at angles of 30° and 90° and analyzed regarding their velocity, energy, point of impact, and expanding characteristics before, during, and after penetrating a car side window (Figs 1 and 2).

In three test series, the physical properties of the projectiles and their individual effects on the target after having penetrated the car window were evaluated. To simulate human tissue, the standard medium gelatin (test series 1) and ballistic soap (test

Abbreviations

Abbreviation	Meaning	Definition
A1	Action 1	Hollow point lead projectile
A4	Action 4	Hollow point lead projectile
A5	Action 5	Hollow point lead projectile
ACP	Automatic Colt Pistol	Hollow point partially jacketed projectile
BLKA	Bayerisches Landeskriminalamt	
DM	German projectile model	Full metal jacket projectile
E_{kin}	Kinetic energy	$E = 1/2 * m * v^2$
GS	Golden Saber	Hollow point partially jacketed projectile
GSb	Golden Saber bonded	Hollow point partially jacketed projectile
HP	Hollow Point	Hollow point projectile
MEN	Metallwerk Elisenhütte GmbH Nassau	
MsVG	Messing Vollgeschoss	Lead projectile made of brass
P.E.P.	Polizei—Einsatz—Patrone	Hollow point lead projectile
PT	Plastik Trainingspatrone	Plastic projectile
PTP	Polizei—Trainings—Patrone	Hollow point lead projectile
PTP/s	Vaiant of the Polizei— Trainings—Patrone	Hollow point lead projectile
SeCa	Security Cartridge, Safe Environment Controlled Action	Hollow point lead projectile
SEK	Sondereinsatzkommando	Special Force Unit of the police
ST	Silver Tip	Hollow point projectile
SX2	Sintox version 2	Full metal jacketed projectile
VM	Vollmantelgeschoss	Full metal jacketed projectile
VMR	Vollmantelrundkopfgeschoss	Full metal jacketed projectile with a rounded nose

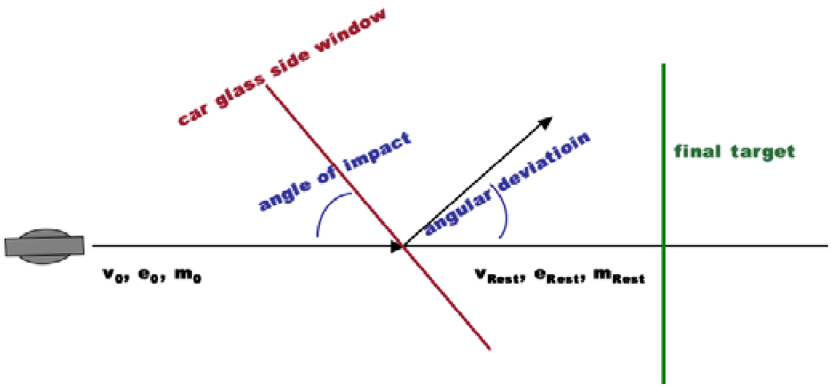

FIG. 1—*Test setup.*

series 2) were used. The examined parameters were shooting angle, velocity, weight before (m_0) and after the shooting (m_{Rest}), expanding characteristics, and penetration depth of each projectile. The velocity was measured by AVL photoelectric barriers "B 471 Typ 4705," and each projectile was being weighed with an electric powder scale "RCBS Powder Pro" Nr. 9303-27 (Frankonia, Würzburg, Germany).

The simulants were placed 25 cm behind the side window. The length of each potential wound channel was measured from the entry point of the bullet to its resting point (= tip of each bullet). In case of a penetrating shot, the maximum length of the simulant was noted.

The results were then compared with the "k-analyzer," a specially developed program to calculate energy transfer into a target by measuring its wound channel and kinetic energy (4).

In a third test series, pig carcasses were used to reproduce a maximum realistic effect in organic tissue. The recently deceased animals were clothed and set in a BMW 3 series behind its window. They were then shot manually with a Glock 26 and 17 at a shooting angle <45°. The entrance wound was situated in the left shoulder–neck region. The animals were X-rayed and an autopsy was performed.

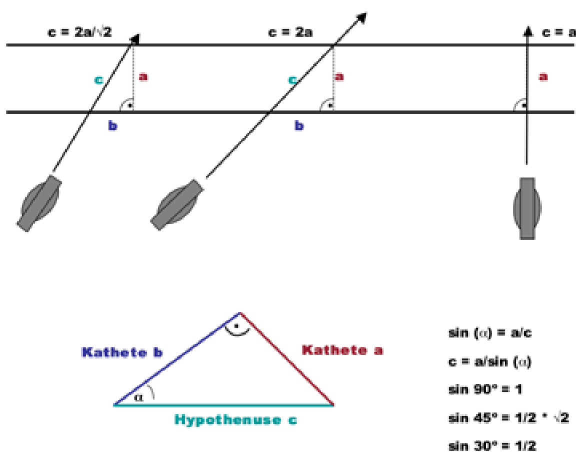

FIG. 2—*Penetration length of the projectile when entering the intermediate target.*

Laminated safety glass side windows type "Saint Gobain" were used as an intermediate target. This type of glass is representative of the glass mostly used in modern vehicles.

TABLE 1—*Test series I: shooting angle at 30° into tissue stimulant: gelatine.*

Nr.	Projectile	Shooting Angle (°)	Velocity v_0 (m/s)	m_0 (g)	m_{Rest} (g)	Energy E_0 (J)	Penetration Depth (cm)	Deviation Angle (°)
1	GSb	30	288	9.5	6.8	394	9	12
2	P.E.P.	30	397	5.9	5.7	465	5	−8
3	MsVG	30	366	7.0	6.9	469	20	−4
4	A4	30	397	6.1	5.5	481	6	5
5	PTP	30	396	5.9	5.9	462	19	−6
6	PTP/s	30	406	5.9	5.8	486	17	0
7	SeCa	30	378	6.5	–*	464	7.5	3
8	A1	30	416	5.6	5.1	485	–	–
9	P.E.P.	30	397	5.9	5.8	463	20	0

*No measurement possible.

Results

The velocities of the projectiles were within the estimated range for handgun ammunition between *c.* 288 and 430 m/sec (Tables 1–3). The slowest projectiles were the ST (293 m/sec) and the GSb (288 m/sec), the fastest ones the A5 (430 m/sec) and P.E.P. (412 m/sec).

The initial energy spread of the projectiles lied between 394 J (GSb) and 564 J (A5). In the pilot study, the projectiles MEN frangible, PT, 45 ACP HP, and 45 ACP VM had unsatisfactory low-energy results (<340 J) and were therefore excluded from further investigations.

The energy levels of the projectiles A5, A4, and P.E.P. were affected most during the penetration process, resulting in comparatively low energy after the glass penetration (Fig. 3).

In the first test series (shooting angle 30°), the MsVG and P.E.P. penetrated 20 cm into the gelatine block, the A4 entered the block 7.5 cm, the P.E.P. only 5 cm.

At a shooting angle of 90°, in the second series, most of the projectiles had wound channels around 20 cm. A reduction in shooting angle lead to wound channels between 6.5 cm (ST) and 20 cm (GS).

Within the organic tissues, the wound channels varied, even within the same projectiles. The P.E.P., for instance, penetrated between 16 and 20 cm into the final target.

A vertical shot through the glass lead to no significant angular deviation. A 30° shooting angle deviated the projectiles between 2° and 7° (P.E.P., GSb, and SX2).

TABLE 2—*Test series II: shooting angle at 30° and 90° into tissue stimulant: soap.*

Nr.	Projectile	Shooting Angle (°)	Velocity v_0 (m/s)	m_0 (g)	m_{Rest} (g)	Energy E_0 (J)	Penetration Depth (cm)
1	P.E.P.	90	412	5.9	5.5	501	>20
2	GS	90	325	8.0	8.0	423	>20
3	A4	90	407	6.1	5.8	505	~20
4	P.E.P.	90	410	5.9	5.8	496	~20
5	Silver Tip	90	294	9.5	6.9	411	>20
6	P.E.P.	30	410	5.9	*	496	11.5
7	GS	30	330	8.0	5.5	436	20
8	A4	30	404	6.1	6.1	498	15
9	Silver Tip	30	293	9.5	5.5	408	6.5
10	A5	30	430	6.1	5.0	564	14
11	DM41	30	349	8.0	6.0	487	20
12	A5	90	421	6.1	*	541	19.5
13	DM41	90	344	8.0	5.8	473	>20
14	P.E.P.	90	411	5.9	*	498	>19
15	GS	90	327	8.0	5.7	428	>19
16	A4	90	410	6.1	6.1	513	>19
17	Silver Tip	90	294	9.5	5.7	411	>19
18	A5	90	423	6.1	6.1	546	>19
19	MsVG	30	352	7.0	7.0	434	~20
20	MsVG	90	373	7.0	7.0	487	>20

*No measurement possible.

TABLE 3—*Test series II: shooting angle at 30° into organic tissue: pig cadavers.*

Nr.	Projectile	Shooting Angle (°)	Penetration Depth (cm)	Penetration	End Location of the Projectile
1	P.E.P	30	20	Soft tissue	Soft tissue between trunk and scapula
2	Action 1	30	30	Soft tissue	Soft tissue left lung
3	GSb	30	17	Soft tissue	Within 2nd vertical spine
4	PTP/s	30	26	Soft tissue	Soft tissue above right scapula
5	GSb	30	18	1st rip	Soft tissue between 1st and 2nd rip
6	P.E.P.	30	16	Soft tissue	In front of chest bone
7	GSb	30	25	2nd rip	Intrapleural
8	P.E.P.	30	30	Soft tissue	Within the thoracic cavity
9	SX2	30	30	Scapula	Penetration of scapula

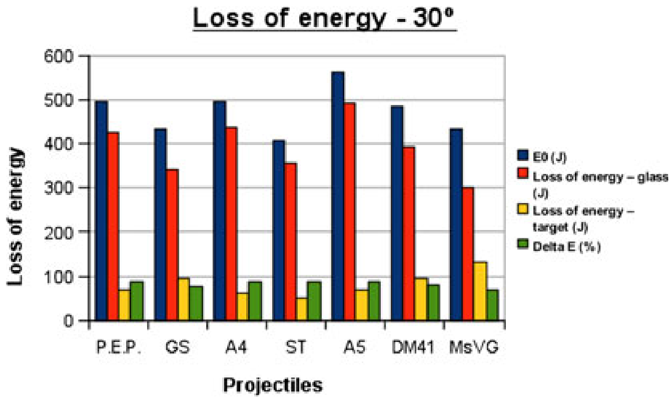

FIG. 3—*Loss of energy at the intermediate and final targets compared to the original energy levels of the projectile.*

The MsVG showed a negligibly low deviation, in contrast to the A1, which had the highest deviations between 15° and 75° and was therefore withdrawn from further investigations.

At a shooting angle of 90°, all expandable projectiles reacted accordingly with a regular mushrooming at a cross-sectional area between 1.0 cm (P.E.P.) and 1.2 cm (A4). In comparison, a lower shooting angle of 30° caused an irregular expanding, in some cases combined with fragmentation of the bullet.

The analysis of the ballistic soap blocks showed similar characteristics throughout the wound channel at shooting angles of 90° and 30°. The largest energy output was noted during the penetration process into the soap block (Fig. 4). In the course of the wound channel, the energy levels then dropped constantly.

No meaningful alteration was noted between the energy transfer of the expandable and nonexpandable ammunition into the final target. At a shooting angle of 30°, the ST had the highest energy transfer per cm into the final target, whereas the GS and DM41 had the longest penetration channel.

Examining the different wound channels in test series III shows that a reliable distinction between the effectiveness of expandable and nonexpandable projectiles is not clearly possible. The entrance wounds had a similar, irregular, and nonadapting wound edge and were situated in the left shoulder–neck region. The wound channels trended downward to the right leaving a length between 16 and 30 cm, depending on the penetrating tissue and final position of the projectile (Table 3).

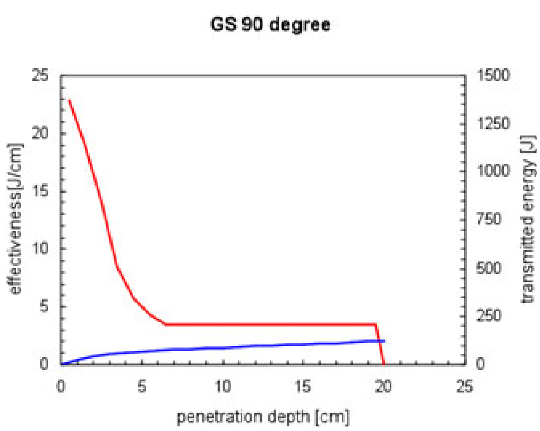

FIG. 4—*Transmitted energy throughout the penetration channel at a shooting angle of 90°.*

Five wound channels were located only in soft tissue (nr. 1, 2, 4, 6, 8—Table 3), three projectiles penetrated a bone (nr. 5, 7, and 9), and one projectile was found within the second cervical spine (nr. 3).

Discussion

By comparing the weight, size, material, design, and velocity of each ammunition and putting them into perspective, it was possible to estimate the effectiveness of each individual projectile. Even though the results at hand are based on a rather low number of tests, it is well known that standardized ballistic test series such as series I and II commonly show an insignificant small variability in basic parameters such as velocity, mass, and angular deviation. Therefore, our results can be compared with a realistic setting.

Shooting Angle

One of the essential results was that the shooting angle has a major influence on the behavior of the projectile, both when penetrating the intermediate target and when hitting the final target afterward.

The smaller the shooting angle, the longer the distance the projectile has to cover in order to pass through the glass window, and the bigger is the energy transfer in the intermediate target (5). A projectile penetrating glass at a 30° angle has to pass a glass distance, which is twice as long as it has to pass at an angle of 90° (Fig. 2). This phenomenon correlates with a rather small velocity after the intermediate target and therefore a minor amount of energy which is left to affect the final target (Fig. 3).

Our research indicates that a vertical glass penetration reduces a projectile's velocity between 20 and 30%. Reducing the shooting angle to 30° causes a loss of velocity between 40 and 90%.

In addition to a significant retardation of the projectile, that is, a higher energy loss at the glass window, the studies show that a smaller shooting angle causes impairment in shooting accuracy. In this context, no differences could be found between expandable and nonexpandable projectiles.

At a shooting angle of 90°, none of the projectiles showed significant changes of angular deviation. It can be stated that when passing the intermediate target vertically and consequently maintaining a high shooting precision, the tested ammunitions have enough energy to cause incapacitation in an individual, depending on the localization of the entrance wound and wound channel (Table 2). But owing to various unalterable variables such as movements of the opponent, slight changes in the shooting angle or distance, an immediate incapacitation cannot be guaranteed. Because of the remaining energy after penetration of the glass window, collateral damages must be taken into account when shooting at an angle of 90°.

A decrease in the shooting angle to 30° led to a decline in shooting precision. Therefore, an optimal accuracy cannot be assured. Collateral damage on the other hand can be precluded with a high certainty. When shooting at a 30° angle, the energy that is left after the penetration process is not high enough to cause an immediate incapacitation in a hostile target (Tables 1 and 2).

Altogether, the nonexpandable projectiles showed a higher shooting precision at lower shooting angles. While expandable projectiles such as the P.E.P. showed no significant angular deviation at a shooting angle of 90°, at a shooting angle of 30°

it had an angular alternation of 8°. The fact that expandable ammunition is affected more than nonexpandable ammunition, when penetrating through glass, has also been examined by Thornton and Cashman (6), with similar results.

Expandable versus Nonexpandable Ammunition

When striking a target, the pressure created in the pit of the projectile of an expandable ammunition forces the material around the inside edge to expand outwards. This process is commonly referred to as mushrooming and depends on the projectile, the target, and the shooting distance (7). In our test series, this phenomenon was noted during the penetration process of the glass window in all expandable ammunition. We could confirm earlier research by Alvefuhr (8) and Burnett (9), who made similar discoveries. Poole et al. (10) detected that a shooting angle of 45° or more is necessary to achieve regular expanding of a penetrating projectile. This could also be seen in our test series. Furthermore, we could confirm that a reduction in shooting angle below 45° results in atypical expanding of the projectiles when penetrating a glass window.

During the penetration of glass, secondary projectiles might occur and cause additional injuries (11). However, this phenomenon could not be seen at our experiments. One of the reasons for this is the fact that on impact safety glass disintegrates in smaller fragments than usual window glass.

The influence of the construction of a projectile on its ballistic interference with an immediate target can be seen on the basis of the GS and GSb. The hollow point ammunitions differ in weight (Δm = 1.5 g) and the construction of their jacket. An electrochemical bonding between the jacket and core of the GSb prevents a separation of the two and results in a heavier and stronger bullet. At a 30° shooting angle, the GS fragmented, whereas the GSb stayed intact, allowing a higher energy transfer into the final target.

Even though the interaction of the different types of ammunition with the intermediate target varied, their terminal ballistic was similar. We could verify the occurrence of atypical entry wounds in the final target, most probably caused by the influence of the intermediate target (12). It is therefore difficult to differentiate expandable and nonexpandable ammunition by their entry wound alone. The fact that the wound channels are complex as well and cannot be differentiated has also been noticed by former researchers such as Harrel (13), Bruns (14), Verhoff and Karger (15), Karger (16), and Di Maio (17). They all came to the conclusion that within organic tissue, the wound channels of expandable and nonexpandable ammunition are very similar, and that the different organic tissue has a greater influence on the resulting channel, than the projectile itself. We could confirm this statement in our studies, especially since the same projectile (P.E.P.) showed different wound channels under almost identical circumstances.

One of the reasons for different wound channels within similar test series is the effect a minor alteration in tissue density and direction of the bullet can have on the extension and course of its remaining wound channel (18).

Effectiveness

Generally, the effect of a gunshot can be influenced by number of factors such as the localization of the entrance wound, the psychological state of the opponent, possible intoxication, and the pathological state of organs (19). For a quick incapacitation, a vital blood-carrying organ needs to be hit. To cause an immediate incapacitation, a hit to the central nervous system is necessary (20).

When correlating the wound channels in test series III with the so-called stopping power of a projectile, it was noted that in just one of the experiments an immediate lethal shot occurred. After entering the upper left neck region, the projectile GSb formed a wound channel progressing slightly cranial and finally ending in the second cervical vertebra, destroying the spinal cord. All the other shots did not injure the spinal cord and were therefore estimated not to be able to cause immediate incapacitation, even if their energy levels indicated a life-threatening potential.

At a shooting angle of 90°, none of the projectiles showed remarkable differences considering their wound ballistic features.

When comparing the different projectiles, which were fired at an angle of 30°, regarding their maximal energy transfer, their average and maximal wound channel effectiveness together with their penetrating dept, it must be said that the GS achieved the highest results. It penetrated the final targets as far as 20 cm and had an average energy transfer of 5 J/cm.

In all of our tests, none of the tested ammunition fulfills the required technical directive of the police, that is, an energy transfer of 30–60 J/cm over a distance of 5 cm.

None of the expandable and nonexpandable projectiles were able to transfer that much energy into the target after having penetrated a glass window.

Conclusion

The degree to which organic tissue in a final target is being destroyed depends mostly on the ammunition, its weight, size, material, design, and velocity.

The ammunition with the highest kinetic energy after having penetrated an intermediate target at a certain shooting angle is the one which shows the shortest interaction with it.

Handgun bullets fired through vehicular side window glass lose substantial energy reducing the effectiveness of the ammunition. This effect is greater when fired at an angle of 30° compared to 90°.

Accuracy is maintained at a 90° angle but seriously impaired at 30°. None of the examined firearm–projectile combinations complied with the demanded wound channel effectiveness of 30–60 J/cm.

The examined ammunition did not maintain sufficient energy levels, high enough to cause an adequate incapacitation of the final target, and at the same time prevent collateral damages.

In consequence for special police operations, such as a hostage situation in a car, an unavoidable exchange of fire implies a high risk for everyone involved. It is therefore advisable to develop alternative strategies for these complex circumstances.

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