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Study on the Wound Ballistics of Fragmentation Protective Vests Following Penetration by Handgun and Assault Rifle Bullets

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ABSTRACT: This experimental study showed that when handgun and assault rifle bullets penetrate fragmentation protective vests (fpv) about one third of all bullets become immediately instable. This results in a shortening of the narrow channel. The diameters of the temporary wound cavities may decrease compared to unprotected persons, but may increase with high-energy bullets. The degree of injuries is thus variable and cannot be predicted in a general manner, but it can be determined empirically for specific bullets as well as for certain types of vests.

KEYWORDS: forensic science, fragmentation protective vest, penetration, handgun bullets, assault rifle bullets, wound ballistics

Purpose of the Study and Definitions

The fragmentation protective vests (fpv) introduced in many armies aim at protecting soldiers in battle areas from flying fragments. Bullets of twist-stabilized weapons will penetrate fpv's. We intended to find out, whether the use of fpv's leads to a variation of the wounding capacity of the bullet and examined the following parameters:

a) stability of bullets
b) changement of the sectional area of bullets
c) energy drop
d) maximal size of the temporary wound cavity

Following, the main terms are explained to those readers, who are not familiar with questions of wound ballistics:

a) stability: a twist-stabilized bullet is stable, if the angle of incidence does not exceed 2 degrees.

b) sectional area of bullets: it changes by deformation or fragmentation

c,d) the temporary wound cavity is a short-time phenomenon of shots in tissue. The narrow channel (n.c.) represents the part of the track of gunshot wounds, when the bullet is stable. At the end of the n.c. the angle of incidence increases, the effective area of the bullet enlarges and more energy is transferred to the tissue. This results in an expansion of the temporary wound cavity.

General Considerations

From a medical point of view there are a few questions that, on the one hand, concern the injury mechanism, and on the other hand, the assessment of the protective effects actually achieved with various protective vests (relative comparison of various types of vests).

Internationally it is usual to determine the critical ballistic velocity, the v_{50}, i.e., that velocity at which there is a 50% probability of penetration. The v_{50} is usually determined with a standard fragment weighing 1.1 g with a diameter of 5.6 mm. The v_{50} is, without doubt, an important parameter and also permits the comparison of the protective effects of various types of vests.

For a comprehensive assessment of wound ballistics the technically oriented determination of the v_{50} (usually with standard fragments) is not sufficient, however.

Theoretically several variants of injury origin must be taken into account:

1. The protective vest withstands the impact, and the person wearing the vest is not hurt.
2. The protective vest is not penetrated, but a slight energy transfer takes place from the point of impact on the soft body armor to the body surface below. Thus a minor injury occurs, such as a bruise with a small hematoma.
3. The protective vest is not penetrated, but substantially deformed. This results in a considerable energy transfer from the bullet onto the body of the person wearing the vest, which the medical literature describes as "behind body-armor blunt trauma effect." In the most unfavorable case this may lead to injuries of the inner organs (heart, large vessels, lungs, liver, kidneys) (see [*1–3*]).

Cases 1 and 2 bring about the desired effect, i.e., the result that the manufacturer of the vest and the person wearing the vest expect from it. These cases only occur, however, if the fragments have the desired velocity (clearly under the v_{50}) or, in the case of bullets, according to the classification of the vest.

4. Frequently, however, fragments will have a higher velocity than the v_{50}, i.e., pierce the vest and penetrate the body. It must also be taken into account that in battle areas the proportion of injuries due to fragments and those due to bullet wounds varies.

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TABLE 1—*Ammunition used*
v_5 = *Velocity m/s*
E_5 = *Energy, joules.*

Ammunition	Bullet weight	v_5	E_5
5, 56 mm S-Patr StG 77	3.61 g	953	1639
9 mm S-Patr P 08	7.98 g	386	594
7, 62 mm S-Patr StG 58	9.47 g	842	3357
7, 62 × 39 mm M-58-CSSR	7.86 g	773	1998

In various scenarios (world wars, jungle war, desert war) the percentage of fragmentation injuries ranges from about 50 to 70%. In other words, a large number of injuries due to small-caliber rifles is to be expected in certain scenarios.

5. If bullets from assault rifles are fired from about 100 m, the vest will always be pierced and the body will sustain a penetrating injury.

An evaluation of the effectiveness of fpv's will therefore also have to include the mechanisms described under 4 and 5. Case 5, which this study investigates, is of special importance as theoretically the penetration of a primary target (in this case the fpv) may give rise to instability and/or deformation of the bullet, which in turn might enhance the severity of the injuries. In no case can it be the intention of a military command to protect soldiers against fragmentation, but at the same time to turn possibly controllable serious gunshot wounds into fatal injuries. At least the restriction of the protective effects of the fpv would have to be considered. An introduction of soft body armor would have to be based also on a benefit-risk analysis and would have to take into account the battle area scenario (predominance of fragmentation injuries or of gunshot wounds).

Materials and Methods

Three different makes of fpv's commercially available for military use at different prices were tested, after the v_{50} of each vest had been determined:

Vest A: nylon; vest weight 4340 g; v_{50} 389 m/s.
Vest B: Kevlar; vest weight 4406 g; v_{50} 506 m/s.
Vest C: Kevlar; vest weight 2928 g; v_{50} 413 m/s.

The ammunition (see Table 1) was selected to represent a cross sample of common calibers of infantry weapons (7.62 × 39 mm/AK; 7.62 × 51 mm/StG 58[2]; 5.56 × 45 mm/StG 77[3]) as well as the most common ammunition of pistols relevant for police and military purposes in Europe (9 × 19 mm para full-jacket soft-core bullet).

In a first trial series stability following vest penetration was tested with indicator paper disks at a range of 10 and 100 m in a total of 56 shots.

As indicator paper we used waxed tissue paper (2 × 2 × 0.0001 m). Ten indicator paper discs were arranged in distances of 0.5 m one behind the other. (The deviation of the circular form of the shotholes shows the instability of the bullet.)

In a second trial series the temporary wound cavities were determined in soap blocks of 30 cm length (range 100 m).

The "wound cavities" thus created were photographed and measured. The results of shots onto soap blocks without a primary target (so-called "reference shots" corresponding to shots at unprotected victims) were compared with shots where the soap block was covered by a fpv that was pierced.

Shots onto gelatin blocks were not performed. According to Sellier and Tikka [*4,5*] both tissue simulators, soap and gelatin, bring about comparable results. Soap block shots were preferred as they are easier to evaluate and to document.

Because of problems at conducting the experiments, we got different numbers of shots at each calibre. An approximation of the number of shots would not lead to other conclusions.

[2]Austrian assault rifle introduced in 1958.
[3]Austrian assault rifle introduced in 1977.

Results

Table 2 shows the results regarding stability behavior according to various parameters (bullets used, range of 10 m versus 100 m, vest types used). In only 18 shots out of all 56 shots (=32%) instability of the bullets occurred in the free flight after the fpv had been penetrated.

Table 3 shows the individual results of the soap block shots. The lengths of the narrow channel and maximum diameters of wound cavities are indicated in mm.

The average values of all three vests were compared with those of the reference shots to answer the question how individual ammu-

TABLE 2—*Stability behavior after vest penetration (number of shots in a total 56 shots).*

Parameter	Stable	Unstable
9 × 19 mm Para	13	6
7.62 × 39 mm	10	4
7.62 × 51 mm	8	3
5.56 × 45 mm	7	5
10 m range	21	9
100 m range	17	9
Vest A	12	9
Vest B	10	7
Vest C	16	2

TABLE 3—*Soap block shots (n.c. = length of the narrow channel in mm; max. = maximal diameter of the temporary wound cavity in mm).*

Ammunition	Vest	n.c.	max.
9 mm Para (P08)	none	200	20
	A	110	15
	B	110	12
	C	70	7
7.62 × 39 mm (AK47)	none	180	60
	A	120	55
	B	120	45
	C	150	45
.308 7.62 mm S (StG 58)	none	130	80
	A	220	70
	B	40	70
	C	110	90
5.56 mm S (StG 77)	none	160	40
	A	120	50
" "	B	10	50
" "	C	88	50

TABLE 4—*Comparison of results of reference shots with the average results of vest shots for the individual bullet types nc = length of the narrow channel in mm max. = maximal diameter of the temporary wound cavity in mm.*

Ammunition nc/max	9 mm Para nc/max.	7.62 × 39 nc/max.	.308 nc/max.	5.56 S nc/max.
Reference shots	200/20	180/60	130/80	160/40
Average 3 vests	97/11	130/48	123/77	73/50

nition types and weapons affect the wound ballistics for the person wearing the vest as compared to an unprotected person (Table 4).

In order to assess the influence of different vest types on parameters of wound ballistics the values for assault rifles (i.e. without 9 mm para) are compared in Table 5 to those for the reference shots of vest types A to C.

Discussion

The question of wound ballistics in the penetration of fpv's raised in the introduction is of tactical as well as forensic significance. Many soldiers wear fpv's in action (e.g., UN troops). Increasingly law enforcement officers are also equipped with soft body armor. As individual observations are very rare in forensic practice, it is difficult to answer this question. The scientific literature on this topic describes wound profiles of bullets and weapons [e.g., *6,7*]—but how is this behavior influenced by a primary target (fpv)? An earlier study in this journal [*8*] dealt with the injury effects in fpv's behavior of the bullets or the impact on the cavitation effects. It is this gap that our study wants to close.

When a vest is penetrated the bullet becomes instable in the ensuing free flight in about one third of all cases (see also Table 2).

Penetrating fpv C, bullets remained stable in most experiments however.

As the scattering of the results indicates, there seems to be another factor that cannot be defined further at present. Empirically instability could neither be assigned clearly to a certain type of ammunition nor—contrary to our expectations—to a certain range. It seems highly probable that there is a considerable influence on the part of the material and how it is processed, which varies not only due to thickness or weight of the material alone.

Instability of the bullets results in a quick energy release over the path. With only one exception, the narrow channel is thus always shortened in the soap block shots.

The following rule can therefore be set up from the point of view of wound ballistics vest penetration shortens the narrow channel as compared to shots at an unprotected person. Generally speaking, this is an unfavorable effect for the person wearing the vest.

TABLE 5—*Comparison of results of reference shots with vest shots for assault rifle bullets. nc = length of the narrow channel in mm max. = maximal diameter of the temporary wound cavity in mm.*

	nc	Max.
Reference shots (3×)	157	60
Vest A (3×)	153	58
Vest B (3×)	57	55
Vest C (3×)	117	62

While the narrow channel is usually shortened, this cannot be said about the maximum diameter of temporary wound cavities. As the individual results in Tables 3, 4 and 5 show, the diameter of the temporary wound cavity is considerably smaller e.g. with handgun shots (9 mm para), which means that injury effects are also reduced. The smaller wound cavity diameter can be explained by the fact that the bullet looses velocity and thus also energy and ultimately injury potential when penetrating the vest. On the other hand, the high-energy bullets of the 5.56 S cartridge showed a volume increase of the temporary cavity, which results in more severe injury effects! As Table 5 shows not only the ammunition, but also the type and processing of the vest worn have a large influence on the smaller or larger volume of the temporary wound cavity.

In summary, the results can be interpreted as follows: when a fpv is penetrated, the person wearing it is not necessarily worse off than an unprotected person as with infantry bullets the shortening of the narrow channel may be offset by a reduced volume of the temporary wound cavity. It may, however, occasionally happen that the injury effects are intensified. These effects as related to individual cases can only be predicted on the basis of empirical studies. As our study has shown, however, predictions are not generally valid for all vest and ammunition types, but are influenced by the specific features of vests an ammunition.

In order to protect the wearer not only against fragments, but also against bullets, the selection of a vest type must also take into account the types of bullets to be expected in view of a specific danger scenario.

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