Z Rechtsmed 81, 309–328 (1978)

Zeitschrift für
Rechtsmedizin
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Experiments on the Penetration Power of Various Bullets into Skin and Muscle Tissue

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Summary. The literature cites values between approx. 50 to as critical velocities for spherical or ogival projectiles. This test was designed to determine the general validity of these values. "Critical velocity" is defined as that velocity, below which no penetration of the skin occurs.

A series of 212 test shots was fired after the powder storage chambers of caliber 9 mm and caliber .45 cartridge cases were altered. With the appropriate charges, velocities varying between 50 and 100 m per sec were achieved. The shots were fired orthogonally into the muscle tissue of the upper thigh of corpses and into a combination of human skin + Mipoplast®. The skin was tightened in a wooden frame and a block of Mipoplast® was directly attached. (Preliminary tests showed that projectiles nearly had the same penetration power in Mipoplast® as in muscle tissue.) The projectile velocities were determined by a „shoot-velociter Re-Tronik" with a resolving power of 10^{-6} sec. Projectiles were considered as having penetrated the skin, when they entered the epidermis for a distance equal to the caliber diameter. In order to determine a ballistic coefficient and a conversion factor, the depth of penetration into muscle tissue of the upper thigh or into Mipoplast® respectively was measured.

The following bullets were used in the tests:

9 mm : lead ball 5.3 g
lead, round nose projectile with a short cylindrical portion, 6.2 g
lead, round nose projectile with a long cylindrical portion, 10.6 g
conical, flat nose projectile 7.9 g
conical, pointed nose projectile 7.9 g

caliber .45 : lead ball 9 g
lead, round nose with a cylindrical portion, 14.7 g

and finally a 4 mm lead ball .47 g.

The projectiles were fired from a Walther pistol P 38, caliber 9 mm Parabellum, a colt pistol, Government 1911 A1, caliber .45 ACP and from a revolver Röhm RG caliber 4 mm Rdz.

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0044-3433/78/0081/0309/$ 4.00

The tests results permit three functional evaluations per series:
(1) optimum parabola of second order,
(2) optimum line (linear regression),
(3) logarithmic function (log. nat.)
The following results were obtained: The penetration power of a projectile does not depend primarily on its velocity, shape or cross-sectional load, but is determined by its mass. The following conclusions could be drawn, concerning lead projectiles fired by us: The greater the mass of a projectile, the lower the „critical velocity" ($v_{cr} = 162.1 \cdot e^{-.629\ m}$). The conversion factor for the penetration power of the examined projectiles comparing skin/Mipoplast® and skin/muscle tissue was determined to be 1.2, i. e. the depth of penetration into skin and muscle tissue is 1.2 times greater than into skin + Mipoplast ®.
An evaluation of these results shows a "loop-hole" in the Gun Control Act, since the legal requirements for the unrestricted acquisition of firearms only considers the kinetic energy of the projectile (less than 7.5 J). However, all lead ball ammunition with diameters of less than 6.2 mm definitely does penetrate the skin at that energy level. Another conclusion is that projectiles fired from unlicensed weapons such as BB guns operated by air pressure, spring or CO_2-cartridge (caliber approx. 4.5 mm) can achieve penetration with as little energy as 4 J. Even if one wants to maintain the present differentiation between exempted weapons and weapons covered by the Gun Control Act, based on the energy level of 7.5 J, the legislature would have to establish a minimum mass for the projectiles. Considering the results obtained, the present limitation of the kinetic energy of the projectiles of 7.5 J alone does not guarantee the level of harmlessness the present law supposes. A projectile mass of less than 1.4 g and a kinetic energy of 7.5 J can reach a level of danger that up now has not been recognized by the legislature. Those findings ought to be considered when licensing weapons according to Para 21 and 25 WaffG (Gun Control Act of the Federal Republic of Germany) as well when prohibiting weapons according to Para 37 WaffG and Para 8, Section 1, Number 1, of the first WaffV (Weapon Regulations).

Key words: Penetration power, of spherical or ogival projectiles – Projectile velocities – Shot, penetration power of bullets.

Zusammenfassung. Die in der Literatur angegebenen Werte für Grenzgeschwindigkeiten (ca. 50–70 m/sec.) kugeliger bzw. ogivaler Geschosse wurden auf ihre Allgemeingültigkeit hin überprüft, wobei als Grenzgeschwindigkeit die Geschwindigkeit eines Geschosses bezeichnet wird, unter der gerade noch kein Eindringen in die Haut erfolgt.
Nach Veränderung von Patronenhülsen der Kaliber 9 mm und Kaliber .45 unter Umgestaltung des Pulverbrennraumes und bei entsprechender Ladung gelangen Schußserien (insgesamt 212 Schüsse), mit Geschoßgeschwindigkeiten zwischen 50–100/m/sec.. Die Schüsse erfolgten orthogonal auf die Oberschenkelmuskulatur von Leichen sowie auf die Medienkombination menschliche Haut/Mipoplast®. Die Haut wurde hierbei in einem Holzrahmen gehalten und ein Mipoplastblock direkt angelegt. (In Vorversuchen zeigten Geschosse in Mipoplast® etwa das gleiche Eindringvermögen, wie in Muskulatur.) Die Geschoßgeschwindigkeiten wurden

jeweils mit einer Meßanlage (Shoot-Velociter Re-Tronik mit einem Auflösungsvermögen von 10^{-6} sec.) gemessen. Als in die Haut eingedrungen wurden Geschosse dann gewertet, wenn sie mit einem kalibergroßen Teil die Epidermis durchdrungen hatten. Die Eindringtiefe in die Oberschenkelmuskulatur bzw. in Mipoplast® zur Errechnung des ballistischen Koeffizienten bzw. eines Umrechnungsfaktors wurde gemessen.

Folgende Geschosse wurden bei den Versuchen verwendet:

Kaliber 9 mm: Bleikugel 5,3 g; Bleirundkopf mit kurzem zylindrischem Teil, 6,2 g; Bleirundkopf mit langem zylindrischem Teil, 10,6 g; Kegelstumpfkopf 7,9 g; Kegelspitzkopf 7,9 g; Kaliber .45: Bleikugel 9 g; Bleirundkopf mit zylindrischem Teil 14,7 g und schließlich eine Bleikugel Kaliber 4 mm 0,47 g. Die Geschosse wurden aus einer Walther-Pistole P 38, Kaliber 9 mm Parabellum, einer Colt-Pistole, Government 1911 A1, Kaliber .45 ACP und einem Revolver Röhm RG, Kaliber 4 mm Rdz. verfeuert.

Aus den Ergebnissen wurden pro Versuchsserie drei Funktionsansätze aufgestellt: Bestparabel 2. Ordnung, Bestgerade (lineare Regression), logarithmische Funktion (log. nat.). Als Ergebnis konnte festgestellt werden: Entscheidend für das Eindringvermögen eines Geschosses in menschliche Haut und Muskulatur ist in erster Linie nicht etwa seine Geschwindigkeit, seine Form oder die Querschnittsbelastung, sondern seine Masse. Dies bedeutet für die von uns untersuchten Bleigeschosse: Je größer die Masse des Geschosses ist, umso kleiner ist die Grenzgeschwindigkeit ($v_{gr} = 162,1 \cdot e^{-0,629\ m}$). Als Umrechnungsfaktor für das an der Kombination Haut/Mipoplast® ermittelte Eindringvermögen der Geschosse gegenüber Haut + Muskulatur wurde der Faktor 1,2 ermittelt, d. h., daß die Eindringtiefe in Haut + Muskulatur das 1,2fache der Eindringtiefe in Haut + Mipoplast® beträgt.

Die Würdigung dieser Ergebnisse zeigt eine „Lücke" im Waffengesetz auf, da die gesetzlichen Voraussetzungen für einen erlaubnisfreien Erwerb von Waffen ausschließlich auf die Bewegungsenergie der Geschosse (unter 7,5 J) abstellen. Alle Bleikugeln mit kleinerem Durchmesser als 6,2 mm dringen jedoch bei dieser Energie mit Sicherheit bereits in den Körper ein. Daraus ergibt sich auch, daß Geschosse, wie sie beispielsweise aus zulassungsfreien Luftdruck-, Federdruck- und CO_2-Waffen (Kaliber ca. 4,5 mm) verschossen werden können, zum Eindringen lediglich eine Energie von 4 J benötigen. Selbst wenn man aber an der Energieschwelle von 7,5 J für die Abgrenzung zwischen privilegierten und voll dem Waffengesetz unterliegenden Waffen festhalten will, müßte der Gesetzgeber auch noch eine Minimalmasse für Geschosse festlegen. Denn nach den hier vorliegenden Ergebnissen reicht die Begrenzung der Bewegungsenergie der Geschosse auf 7,5 J nicht aus, um denjenigen Grad von Ungefährlichkeit zu gewährleisten, von dem das Gesetz derzeit ausgeht. Bei Geschoßmassen von weniger als 1,4 g und einer Bewegungsenergie von 7,5 J kann durchaus ein Grad von Gefährlichkeit erreicht werden, den der Gesetzgeber bisher nicht zu berücksichtigen vermochte. Diesem Umstand sollte sowohl im Zulassungsverfahren nach §§ 21 und 25 WaffG, wie auch bei den Verboten nach § 37 WaffG und § 8, Abs. 1, Nr. 1 der 1. WaffV entsprechend Rechnung getragen werden.

Schlüsselwörter: Schuß, Geschoßgeschwindigkeit – Geschoßgeschwindigkeiten – Durchschlagkraft, bei verschiedenartigen Projektilen.

In previous publications on the penetration power of projectiles into the skin, the velocity is always considered to be decisive, and the critical velocities are reported to be approx. 50 to 70 m per sec (Journee, 1907; Sellier, 1969; Mattoo, 1974; Sellier, 1976). The "critical velocity" of a projectile is defined as that velocity below which no penetration of skin occurs. Those data on the critical velocity exclusively refer to spherical and ogival projectiles.

The relatively few experiments, reported in literature, and the exclusive application of spherical bullets caused us to create a broad experimental base by the use of projectiles with various shapes and calibers. Especially we were interested in the question of if the previous data on the critical velocity are generally valid, or if a dependence on the shape of projectiles exists, as it was presumed by Mattoo (1974) and Sellier (1976).

We dealt with two kinds of questions:

I. The determination of the velocity of various projectiles of different calibers, above which a penetration of human skin occurs,

II. the measurement of the depth of penetration of projectiles into muscle tissue and Mipoplast® for

1. the calculation of the ballistic coefficient C_B, and
2. the determination of the conversion factor u for Mipoplast®: muscles.

Methodology

A. Test Procedure

a) Series of shots were fired at the upper thighs of various corpses at a distance of 1 meter and by interposition of the subsequently described measuring instrument. The following bullets were used:

lead ball, caliber 9 mm, 5.3 g, A = .64 cm^2 (projectile no. 1); lead, round nose bullet with a short cylindrical portion, caliber 9 mm, 6.2 g, A = .64 cm^2 (projectile no. 2); lead, round nose bullet with a long cylindrical portion, caliber 9 mm, 10.6 g, A = .64 cm^2 (projectile no. 3); conical, pointed nose bullet, caliber 9 mm, 7.9 g, A = .64 cm^2 (projectile no. 5).

b) Pieces of human skin were tightened in a wooden frame (16 x 16 cm) (Mattoo, 1974). The pieces of skin were removed from the upper part of the buttock of corpses together with the hypodermic fatty tissue according to the mark of a rectangular stamp. The age of the bodies was between 40 and 50 years. Apart from some "fresh" parts of the skin, deeply frozen ones were mainly used after thawing. (Preliminary tests did not reveal a conclusively different behaviour.)

The pieces were stretched in the wooden frame by means of a simple suture. In order to avoid too strong or too weak a tension on the pieces of skin, the conformity of the stamp area with the original size was essential. The wooden frame with the stretched piece of skin was fixed at a distance of 15 cm behind the last "paper barrier" of the measuring instrument. (Particular measuring installation was by means of electrically conducting paper barriers of the Re-Tronik Company).

A cylindrically moulded block of plastic material (Mipoplast® PVC 5319/1099 Dynamit Nobel AG) was attached directly to the piece of skin, which on an average had a total thickness of approx. 2 cm in order to create a unit of skin and "muscle tissue".

Fig. 1. Projectiles of caliber 9 mm (nos. 1–5)

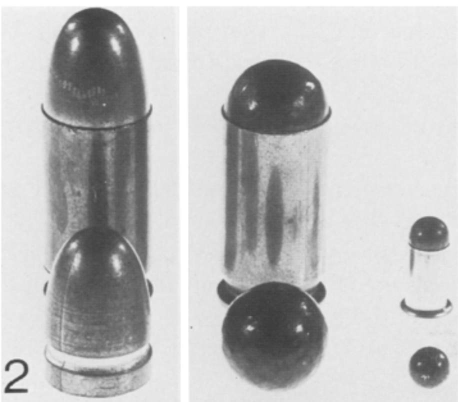

Fig. 2. Projectiles of caliber. 45 ACP and caliber 4 mm
Fig. 3. Cross section of a 9 mm parabellum case with a partial casting and a cylindric hole

Shots were orthogonally fired at the piece of skin from a constant distance of 1 m. The pieces of skin were shot at in such a manner as to avoid errors due to too closely grouped entry-holes. Because of larger exit-holes in the reverse hypodermic fatty tissue, relatively large distances had to be kept.

In preliminary tests, the behaviour of Mipoplast® resembled muscle tissue more than gelantin blocks of 20 or 25 % did. Projectiles of the same caliber with the same energy showed approximately the same depth of penetration into the muscle tissue of the upper thigh as into Mipoplast®. Another advantage is due to the fact that "loops" of the projectiles – occuring very often in gelantin – could be excluded.

Each projectile passed a measuring range of 50 cm before impacting on the skin. The measurement of the "traverse time" was carried out by means of the Re-Tronik-Shoot Velociter with a resolving power of 10^{-6} sec.

B. Ammunition

a) Projectiles. The following projectiles were used (see Fig. 1 and 2):

Projectile no. 1: lead ball, caliber 9 mm, 5.3 g, A = .64 cm^2

Projectile no. 2: lead, round nose bullet with a short cylindrical portion, caliber 9 mm, 6.2 g, A = .64 cm^2

Projectile no. 3: lead, round nose bullet with a long cylindrical portion, caliber 9 mm, 10.6 g, A = .64 cm^2

Projectile no. 4: conical, flat nose bullet, caliber 9 mm, 7.9 g, A = .64 cm^2

Projectile no. 5: conical, pointed nose bullet, caliber 9 mm, 7.9 g, A = .64 cm^2

Projectile no. 6: lead ball, caliber .45 (= 11.46 mm), 9.0 g, A = 1.026 cm^2

Projectile no. 7: lead, round nose bullet with a cylindrical portion, caliber .45 (= 11.46 mm), 14.7 g, A = 1.026 cm^2

Projectile no. 8: lead ball, caliber 4 mm, .47 g, A = .145 cm^2

(A indicates the cross sectional area of the projectiles.)

b) Elaboration. 9 mm Parabellum cartridges and cartridge cases of caliber .45 ACP were partly filled up with an alloy of lead and tin (2:1), after previous tinning. The resulting surface was faced and provided with a fine cylindrical flash hole (diameter .18–.20 cm) (see Fig. 3).

For loading, approx. 20 to 50 grains of powder were used (propellant charge Bofors PK 5).

The loading and the flash hole were covered by a small and thin (.02–.03 cm) cardboard disc. For ignition RWS boxer primers were utilized.

The altering of the cartridges, especially the width of the flash hole and the elaboration, were based on numerous preliminary tests. The determined width of the flash hole guaranteed a complete combustion of the gun powder.

C. Weapons

The following weapons were utilized –

for projectiles no. 1–5: Walther pistol P 38, caliber 9 mm, Parabellum

for projectiles no. 6–7: Colt pistol Government 1911 A1, caliber .45 ACP

for projectiles no. 8: Revolver Röhm RG, caliber 4 mm Rdz.

D. Series of Shots

With each type of projectile, series of various loadings were fired. A projectile was considered as having penetrated the skin, when it entered the epidermis at least for a distance equal to the caliber diameter. Superficial injuries were counted as ricochets.

a) The following shots were fired onto the reverse of the upper thigh of corpses and evaluated:

Projectile no. 1:	lead ball, cal. 9 mm, 5.3 g	4[1] shots, 6[2]
Projectile no. 2:	lead, round nose, cal. 9mm, 6.2 g	2[1] shots, 18[2]
Projectile no. 3:	lead, round nose, cal. 9 mm, 10.6 g	9[1] shots, 8[2]
Projectile no. 5:	conical, pointed nose, cal. 9 mm, 7.9 g	2[1] shots, 7[2]

b) The following shots were fired onto the mixed medium skin + Mipoplast® and evaluated:

Projectile no. 1:	lead ball, cal. 9 mm, 5.3 g	38[3] shots, 10[4]
Projectile no. 2:	lead, round nose, cal. 9 mm, with a short	

	cylindrical portion, 6.2 g	32[3] shots, 1[4]
Projectile no. 3:	lead, round nose, cal. 9 mm, with a long cylindrical portion, 10.6 g	35[3] shots, 1[4]
Projectile no. 4:	conical, flat nose, cal. 9 mm, 7.9 g	32[3] shots, 0[4]
Projectile no. 5:	conical, pointed nose, cal. 9 mm, 7.9 g	26[3] shots, 6[4]
Projectile no. 6:	lead ball, cal. .45, 9.0 g	23[3] shots, 3[4]
Projectile no. 7:	lead, round nose, cal. .45, 14.7 g, with a cylindrical portion	16[3] shots, 0[4]
Projectile no. 8:	lead ball, cal. 4 mm, .47 g	10[3] shots, 6[4]

E. Approximation Curves

Each depth of penetration s (in cm) and the velocity (in m per sec) were represented in a graph. Three functional evaluations per test series were established in order to determine a functional relation between the depth of penetration and the velocity:

1. optimum parabola of the second order
2. optimum line (linear regression)
3. logarithmic function (log. nat.)

An optimum parabola is defined as an approximation function of the second order between the depth of penetration s and the velocity v. In mathematical terms:

(1) $s = av^2 + bv + c$

For physical reasons, the graph of such a function can only be a parabola opened downwards, in consequence, mathematics require a negative value for the coefficient a in front of the term v^2.

The functional equation (1) can be transformed into

(2) $s = c\,(v - v_S)^2 + e$

The factor c determines the degree of curvature of the parabola, the sign of c, however, the direction of curvature, and v_S the velocity, at which the maximum depth of penetration e (in cm) occurs. The highest point of the parabola is also called the vertex. The vertex of such a ballistic curve indicates the values, up to which the mathematically established optimum parabola can be appplied for ballistic purposes. The example of the optimum parabola for projectile 1 (lead ball, caliber 9 mm, 5.3 g) shall illustrate this mathematical consideration.

Based on data from 14 shots fired, the following functional equation was formed for projectile 1:

(3) $s = -.00047\,(v - 292.7)^2 + 23.2$

The scope of validity of (3) is limited by the values of $v = 70.5$ m per sec (resulting in $s = 0$) and of $v = 292.7$ m per sec (vertex of the parabola).

Nearly any function can be approximated in a relatively small region by a quadratic or a linear function, or, on account of the shape, in this case, preferably by a log. nat.-graph (Sellier, 1976). As all series exhibited a more or less curved tendency in their sequence of points, either the optimum parabola or the log. nat.-graph was considered to be the better approximation, compared to the linear function (optimum line). For the purpose of control and comparison, however, the so-called optimum lines were established for the eight series, too. In five cases they revealed a correlation coefficient in the range $.92 \leqslant r \leqslant .99$, and only in three cases $r < .9$.

[1] = 30– 50 m per sec
[2] = 50–100 m per sec
[3] = 50–100 m per sec
[4] > 100 m per sec

1 α = optimum parabola of the series of shots for projectile no. 1
1 β = optimum line of the series of shots for projectile no. 1
1 γ = optimum log. nat.-graph of the series of shots for projectile no. 1
(For projectile no. 2 up to projectile no. 8 respectively).

The representations for the projectiles 2 and 4 are chosen as illustrative examples:

(4) 2 α) $s = -.00345\,(v - 122.7)^2 + 10.4$ $v_{cr} = 67.8$ m per sec (calculated)

(5) 2 β) $s = .22\,v - 13.9$ $v_{cr} = 64.5$ m per sec

(6) 2 γ) $s = 19.54 \cdot \ln \frac{v}{66.4}$ or

$s = 2.02 \cdot \frac{m}{A} \cdot \ln \frac{v}{66.4}$ $v_{cr} = 66.4$ m per sec

with m = mass of projectile [g]
A = cross sectional area [cm^2]
s = depth of penetration [cm]

(7) 4 α) $s = -.00133\,(v - 179.8)^2 + 20.7$ $v_{cr} = 55.1$ m per sec

(8) 4 β) $s = .26\,v - 13.6$ $v_{cr} = 52.3$ m per sec

(9) 4 γ) $s = 21.16 \cdot \ln \frac{v}{56{,}2}$ or

$s = 1.71 \cdot \frac{m}{A} \cdot \ln \frac{v}{56.2}$ $v_{cr} = 56.2$ m per sec

Both examples reveal a far-reaching consistency of the three methods of representation in the calculated values for v_{cr}. The clearest representation is the log. nat.-graph., whereas the α-graph has proven to be very useful for the determination of v_{cr}.

Results and Discussion

a) Corpse
Projectile
1) no penetration

2)

v	64.3	76.5	77
s	1.3	9.6	17.4

3)

v	48.4	52.1	52.9	53.4	54.1	55.9	64.9
s	6.6	5.6	2	13.1	10	6.7	7.6

5)

v	53.7	55.3	56.6	59.2	74.1	77.5
s	~1	~1	~1	~1	7	9

b) Skin and Mipoplast®

1)

v	95.4	123.1	144.2	135.5	158.3	184.4	152.3	152.5	129.5	90.6	89.7	114
s	5.2	7.5	13.1	12.7	10.5	17.9	15.1	16.9	11.4	6.6	3	8.2

v	112.8	94.3
s	7.8	3.1

2)

v	65.2	66.6	68.4	69.3	70.8	73.6	73.7	74.7	73.5	73.6	75.6	77.3	80.3	80.8
s	0[5]	0[5]	0[5]	0[5]	0[5]	0[5]	0[5]	0[5]	3.7	4.0	4.2	4.9	5.0	4.7

[5] no "penetration" but skin injured

v	94.7	118.8
s	7.2	10.4

3)

v	70.7	66.7	81.8	57.1	56.8	63.9	94.2	78.5	86.1	131.9
s	5.5	5.8	9.7	2.6	2.5	5.5	10.9	5.4	9.2	13.9

4)

v	75	87.5	74.3	67.7	65.7	86.9	96	94.8	89.1	79.8	93.8	79.3	83.7	94.6
s	6	7.7	2.7	4.4	3.7	10.1	13.1	9.6	9.2	9.6	11.3	8.1	9.1	10.3

5)

v	64.4	80.2	116.4	79.2	93.2	108.6	64.4	83.3	76.9	71.9	61.5	68.3	69.9	64.8
s	3.2	6.2	11.3	7.0	6.6	11.9	1.9	6.4	1.7	2.0	1.0	1.3	0.9	1.3

v	60.7	67.3	67.4	101.6	81.2	104.6	105	107.7	95.6
s	1.3	2.9	5.7	12.7	9.7	12.2	12.7	12.7	12.2

6)

v	114.4	108.3	76.4	87.5	140.3	82.3	85.1	77.9	84.2
s	9.6	9.3	3.7	6.2	13.4	3.5	4.5	4.9	4.0

7)

v	73.3	75.1	75.6	69.4	59.2	95.7
s	6.2	5.8	7.8	5.0	3.7	8.2

8)

v	124.4	120.6	149.7	136.9	149.8	133.5
s	.2	.2	3.6	1.9	3.4	1.9

I. Critical Velocity

The following graphs (shaded sections) show the critical velocities of the various projectiles. The shots are subdivided into r = "ricochets" and p = "penetrators".

The first diagramm covers all the shots of the different projectiles no. 1, 2, 3, and 5 onto the reverse of the upper thigh of various corpses (see Fig. 4 a). The second diagramm covers all the shots on the mixed medium skin + Mipoplast® for the various projectiles no. 1 thru 8 (see Fig. 4 b).

Obviously, there is a partial superimposition of the region of penetration with the region of non-penetration. Accordingly, more detailed statements are only possible by means of approximation curves.

Deriving the calculable critical values of v from the three approximation functions (see Table 1) for each projectile and taking the arithmetic mean, a good and realistic value is obtained.

Thus, the test series yielded the following critical velocities (see Table 2).

Comparing those velocities to the respective masses of projectiles, it becomes obvious that the greater the mass the smaller the critical velocity v_{cr} (see Fig. 5).

Sellier (1976) referred to a Sperraza-Konakis publication (1968), according to which v_{cr} is not constant for bodies of the same geometry, but decreases with an increasing cross sectional load S. This can be confirmed by the above mentioned values.

Table 1. Approximation functions for v_{cr} of the various projectiles no. 1 thru 8. Critical velocity v_{cr} (m per se)

Projectile no.	optimum parabola	optimum line	log. nat.
1	70.55	62.00	73.46
2	67.77	64.54	66.39
3	46.98	32.71	45.63
4	55.05	52.31	56.22
5	59.32	55.40	58.98
6	54.90	52.50	62.64
7	46.10	25.50	39.48
8	120.24	120.10	120.53

Table 2. Critical velocity v_{cr} for the various projectiles

Projectile no. 1 (5.3 g)	v_{cr} = 68.7 m per sec
Projectile no. 2 (6.2 g)	v_{cr} = 66.2 m per sec
Projectile no. 3 (10.6 g)	v_{cr} = 41.8 m per sec
Projectile no. 4 (7.9 g)	v_{cr} = 54.5 m per sec
Projectile no. 5 (7.9 g)	v_{cr} = 57.9 m per sec
Projectile no. 6 (9.0 g)	v_{cr} = 56.7 m per sec
Projectile no. 7 (14.7 g)	v_{cr} = 37.0 m per sec
Projectile no. 8 (.47 g)	v_{cr} = 120.3 m per sec

In Figure 6, to each value of S, the respective value of v_{cr} is correlated. As an approximation graph,

$$v_{cr} = 277.7 \cdot e^{-.482\sqrt{S}}$$

can be applied, which clearly reveals the inverse relationship between v_{cr} and S.

Even more interesting is the relation between v_{cr} and the mass. Taking the mass m (g) as an x-axis and v_{cr} (m per sec) as a y-axis, the following graph can be obtained for the above mentioned values (see Fig. 5).

Even more clearly than in the graphical representation of the dependence on the cross sectional load (see Fig. 6), the relation between mass and critical velocity of a projectile can be seen here. A good approximation formula for that relation is represented in equation (10):

$$(10) \quad v_{cr} = 162.1 \cdot e^{-.38\sqrt{m}}$$

The most remarkable fact of this functional equation is the complete independence of v_{cr} from the caliber and the sole dependence on the mass. This relationship permits the calculation of the respective critical velocity for a projectile of the known mass m, completely neglecting the shape of the projectile in the scope of our investigations (exclusively applicable to lead bullets).

The following examples, calculated for common calibers, are to demonstrate the practical value of that formula:

1. cal. 6.35 m = 3.3 g v_{cr} = 81.3 m per sec E_{cr} = 10.9 J
2. cal. 7.65 m = 4.8 g v_{cr} = 70.5 m per sec E_{cr} = 11.9 J
3. cal. 9 mm sh. m = 6.0 g v_{cr} = 63.9 m per sec E_{cr} = 12.3 J
4. cal. 9 mm m = 8.0 g v_{cr} = 55.3 m per sec E_{cr} = 12.2 J
5. cal. 9 mm m = 10.6 g v_{cr} = 47.0 m per sec E_{cr} = 11.7 J (lead)

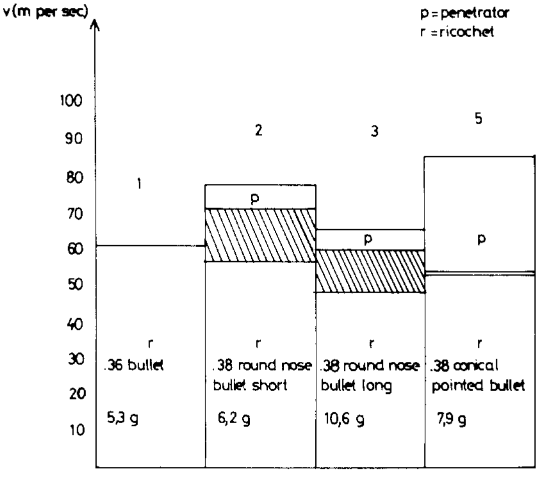

Fig. 4a. Behaviour of the projectiles nos. 1, 2, 3, and 5 on the corpse (reverse upper thigh)

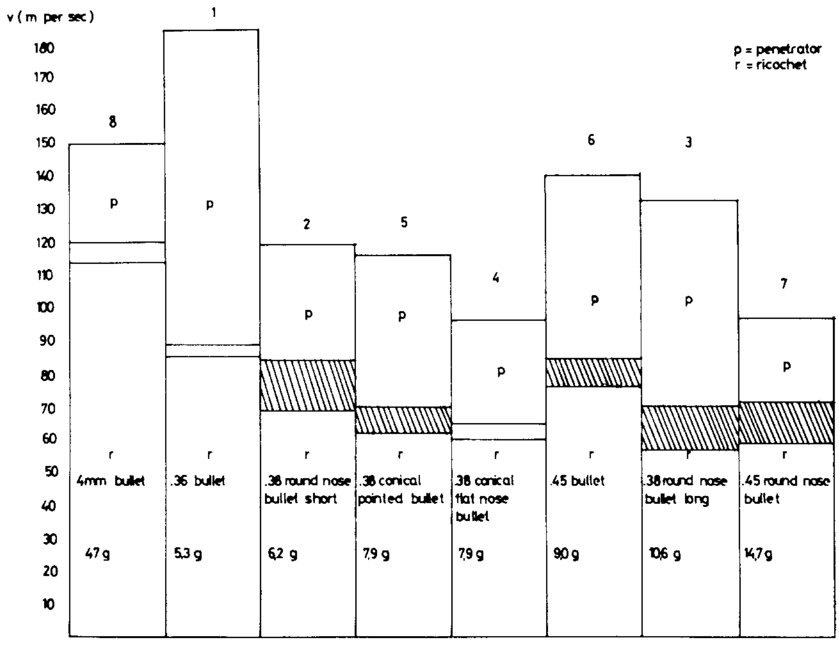

Fig. 4b. Behaviour of the projectiles nos. 1–8 on skin + Mipoplast®

6. cal. .45 (= 11.46 mm)
(sphere) m = 9.0 g v_{cr} = 51.8 m per sec E_{cr} = 12.1 J

From the mass of the projectile, v_{cr} can be calculated, and the formula

$$(11) \quad E_{cr} = \frac{m}{2000} \cdot v_{cr}^2$$

permits the determination of the minimum energy, required for the penetration of skin.

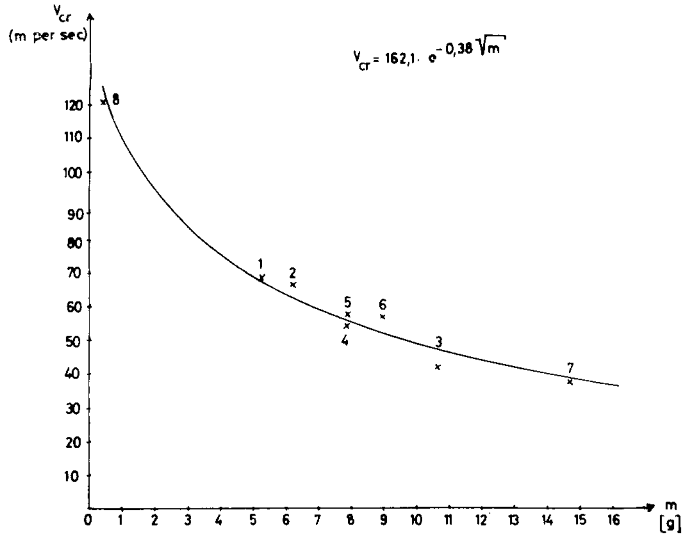

Fig. 5. Critical velocity v_{cr}, depending on the mass m (projectiles nos. 1–8)

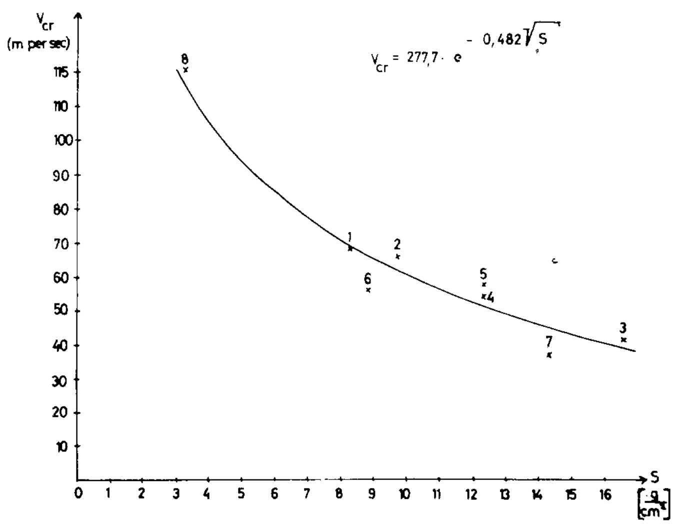

Fig. 6. Critical velocity, depending on the cross sectional load $S = \frac{m}{A}$ (g/cm^2) for projectiles nos. 1–8

For the scope of the two formulas (10) and (11), it seems to be irrelevant, whether the projectiles are manufactured of lead or steel or of lead with a steel jacket, because in 6 out of 8 compared cases, spherical shaped bullets were examined, and on the other hand, no deformation of the lead bullets occured in the range of investigation of skin and muscles, which might have caused different results in comparison to steel bullets.

Sellier (1969) quotes two types of projectiles from an investigation by Journee (1907) with the following data:

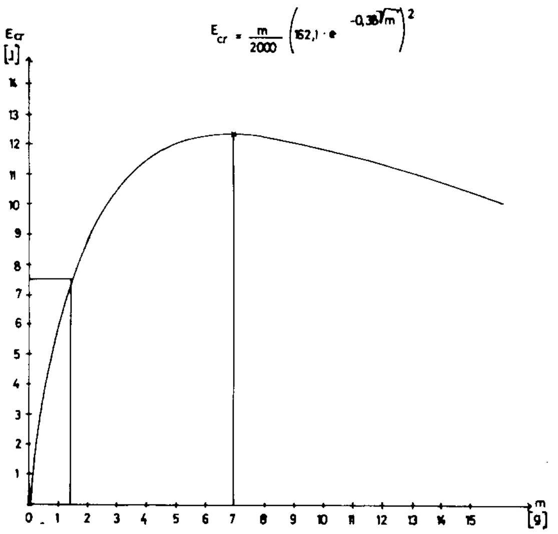

Fig. 7. Critical energy E_{cr}, depending on the mass m (g) of a projectile. Especially marked are the mass of 1.4 g, corresponding to an energy of 7.5 J, and the maximum critical velocity at 6.9 g

a) steel bullet 3.2 mm, m = .13 g, v_{cr} = 50 m per sec, E_{cr} = .16 J
b) lead bullet 4.4 mm, m = .5 g, v_{cr} = 48 m per sec, E_{cr} = .6 J

Projectile (a) is reported to have just penetrated the skin at a velocity of 50 m per sec, projectile (b), however, at a velocity of 48 m per sec did not.

Applying the above mentioned formulas (10) and (11) to the two types of projectiles, not considering their material (steel or lead), because (10) and (11) only depend on the mass, the following results were obtained:

a) steel bullet 3.2 mm, m = .13 g, v_{cr} = 141.3 m per sec, E_{cr} = 1.3 J
b) lead bullet 4.4 mm, m = .5 g, v_{cr} = 123.9 m per sec, E_{cr} = 3.8 J

Considering this calculation and our experimental results, the steel bullet (a) cannot have penetrated the skin at the above mentioned velocity (according to our definition).

The lead bullet (b) corresponds rather exactly to the projectile no. 8 (4.3 mm, m = .47 g). For that type no. 8, a critical velocity of 120.3 m per sec was experimentally determined by a series of measurements. That explains the fact that, according to Journee, the bullet (b) did not yet penetrate the skin at a velocity of 48 m per sec. Moreover, the experiment proves the correctness of the values of v_{cr}, calculated by means of formulas (10) and (11).

Regarding Figure 1, it is obvious that the projectiles nos. 4 and 5 (conical, flat nose and conical, pointed nose) are not spherical. On purpose, they have been chosen to be different from he other six types of projectiles. In spite of their diverse shapes, their ballistic values nearly homogeneously match with the graphical representation of Figure no. 5. They are represented in the same way by formula (10) as the values of the other spherical types.

Consequently, the supplement of "spherical shape" can be omitted in the scope of our investigations, considering the subject of v_{cr}. By the graphical representation of the critical velocity as a function of the energy, no obvious mathematical relation $v_{cr} = f(E)$ can be found. Accordingly, the impact velocity is not decisive for the penetration of the skin, as it was already stated by Sellier (1969).

The energy, at which a projectile can just penetrate the skin, is calculated by formula (11), including formula (10),

$$(12) \quad E_{cr} = \frac{m}{2000} \cdot (162.1 \cdot e^{-.38\sqrt{m}})^2$$

or transformed

$$E_{cr} = \frac{162.1^2}{2000} \cdot m \cdot e^{-.76\sqrt{m}}$$

Forming the differential quotient dE/dm, the following equation is obtained:

$$\frac{dE}{dm} = \frac{162.1^2}{2000} \cdot e^{-.76\sqrt{m}} \cdot \left(1 - \frac{.76 \cdot m}{2 \cdot \sqrt{m}}\right)$$

In order to obtain a relative maximum of E_{cr}, the quotient dE/dm is equated as zero, resulting in m = 6.9 g.

The significance of that particular mass m = 6.9 g can be easily derived from the graphical representation of (12) (see Fig. 7). For a projectile of that mass, the maximum critical energy is required for the penetration of the skin. For all other masses, the corresponding values of E_{cr} are lower. Apart from that, it can be derived from the graph (Fig. 7) that e. g. a projectile of the mass of 14 g requires the same critical energy of 10.7 J for penetration as a projectile of the mass of 3.1 g.

II. Depth of Penetration

1. Ballistic Coefficient C_B

Sellier (1976) mentions the formula for the depth of penetration into soft tissue (such as skin and muscles), commonly referred to in literature:

$$(13) \quad s = \frac{1}{\alpha} \ln \frac{v}{v_{cr}} \quad \text{, with}$$

$$(14) \quad \alpha = \frac{\rho}{2} \cdot C_B \cdot \frac{A}{m}$$

Sellier (1976) has taken the ballistic coefficient C_B from the American literature. Until recently, those American values for C_B seemed to be constant, only depending on the nature of the penetrated material. That constance of the C_B-values was called in question for good reasons by Sellier (1976).

The representation of s in dependence on ln v was already designated as the third way of description or the γ-approximation formula.

In the following table, those functional equations are listed:

1 γ) m = 5.3 g A = 0.64 cm²

$$s = 19.46 \ln \frac{v}{73.5} \quad \text{or}$$

$$s = 2.35 \cdot \frac{m}{A} \cdot \ln \frac{v}{73.5}$$

2 γ) m = 6.2 g A = 0.64 cm²

$$s = 19.54 \ln \frac{v}{66.4} \quad \text{or}$$

$$s = 2.02 \cdot \frac{m}{A} \cdot \ln \frac{v}{66.4}$$

3 γ) $m = 10.6\ g \quad A = 0.64\ cm^2$

$$s = 13.80 \ln \frac{v}{45.6} \quad \text{or}$$

$$s = 0.83 \cdot \frac{m}{A} \cdot \ln \frac{v}{45.6}$$

4 γ) $m = 7.9\ g \quad A = 0.64\ cm^2$

$$s = 21.10 \ln \frac{v}{56.2} \quad \text{or}$$

$$s = 1.71 \cdot \frac{m}{A} \cdot \ln \frac{v}{56.2}$$

5 γ) $m = 7.9\ g \quad A = 0.64\ cm^2$

$$s = 20.15 \ln \frac{v}{59.0} \quad \text{or}$$

$$s = 1.63 \cdot \frac{m}{A} \cdot \ln \frac{v}{59.0}$$

6 γ) $m = 9\ g \quad A = 1.026\ cm^2$

$$s = 16.43 \ln \frac{v}{62.6} \quad \text{or}$$

$$s = 1.87 \cdot \frac{m}{A} \cdot \ln \frac{v}{62.6}$$

7 γ) $m = 14.7\ g \quad A = 1.026\ cm^2$

$$s = 9.75 \ln \frac{v}{39.5} \quad \text{or}$$

$$s = 0.68 \cdot \frac{m}{A} \cdot \ln \frac{v}{39.5}$$

8 γ) $m = 0.47\ g \quad A = 0.145\ cm^2$

$$s = 16.10 \ln \frac{v}{120.5} \quad \text{or}$$

$$s = 4.97 \cdot \frac{m}{A} \cdot \ln \frac{v}{120.5}$$

Extracting the respective ratio $\frac{m}{A}$ out of the coefficient before ln in the first equations, the following functional equation can be obtained:

$$(15) \quad s_i = c_i \cdot \frac{m_i}{A_i} \cdot \ln \frac{v}{v_{cr_i}}$$

for the various projectiles nos. i = 1, 2, 3, 4, 5, 6, 7, 8.

Sellier (1976) stated the independence of the factor c from the size of the projectile, because the ratio $\frac{m}{A}$ (= characteristic size of the projectile) could be extracted out of the coefficient before ln.

According to equation (15), each of the eight projectiles is related to a specific value for m, A, v_{cr}, and c. The graphical representation of c = f (m) reveals a specific dependence of the factor c on the projectile (see Fig. 8).

The following interesting relationship can be obtained, taking the mass of the projectile as the abscissa and the corresponding c-value as the ordinate:

$$(16) \quad c = 8.979 \cdot e^{-.629\sqrt{m}}$$

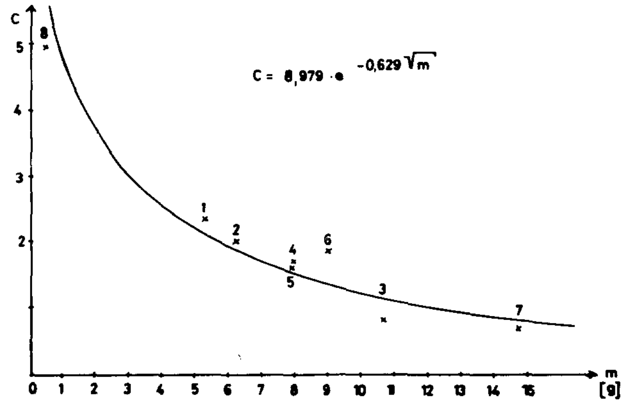

Fig. 8. c-value, specific of the projectile, depending on the mass m of the projectiles nos. 1–8

Considering equation (16), the factor c is not at all constant, but still depends on the mass m of the projectile. To each mass m, a certain c-value is related and vice versa.

From the mass of a known type of projectile, the corresponding c-value can be calculated by means of equation (16).

Example: m = 4.8 g (e. g. a projectile in caliber 7.65)
From (16), it follows: c = 2.3
Considering (10): v_{cr} = 70.5 m per sec.

Thus for the depth of penetration for that projectile, the following equation can be formed by means of (15):

(17) $s = 2.3 \cdot \frac{m}{A} \cdot \ln \frac{v}{70.5}$, where the factor

m can be replaced by 4.8 g.

(18) $s = 2.3 \cdot \frac{4.8}{A} \ln \frac{v}{70.5}$ or

(19) $s = \frac{11.04}{A} \cdot \ln \frac{v}{70.5}$

The last equation contains the cross section A, or in other words, the corresponding caliber, as the only specific value for the projectile.

If that caliber is known exactly, e. g. d = .765 cm, the value of .46 cm^2 for A has to be introduced into equation (19). For the calculation of the depth of penetration for that projectile, the following exact equation can be obtained:

(20) $s = 24.0 \cdot \ln \frac{v}{70.5}$

According to that formula, the caliber 7.65, m = 4.8 g, does just not penetrate the skin at a velocity of 70.5 m per sec, but does penetrate it for 3 cm at 80 m per sec, and already for 5.9 cm at 90 m per sec.

Introducing equations (14) and (13), the following equation can be obtained:

(21) $s = \frac{2}{\rho \cdot C_B} \cdot \frac{m}{A} \ln \frac{v}{v_{cr}}$

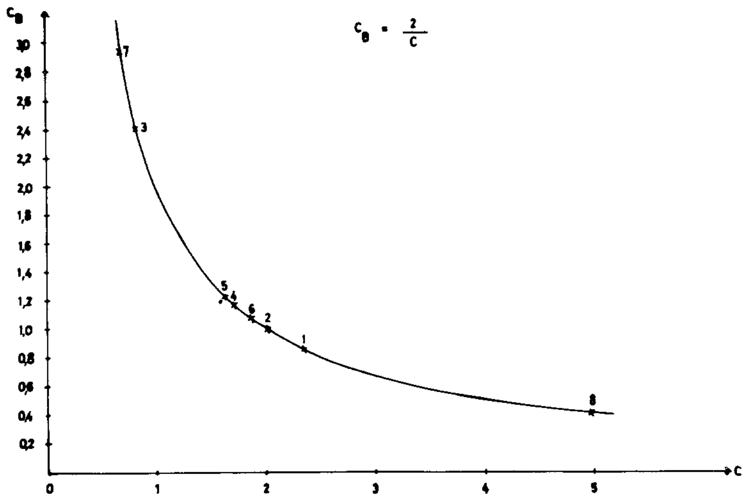

Fig. 9. Ballistic coefficient C_B, depending on the c-value, specific of the various projectiles

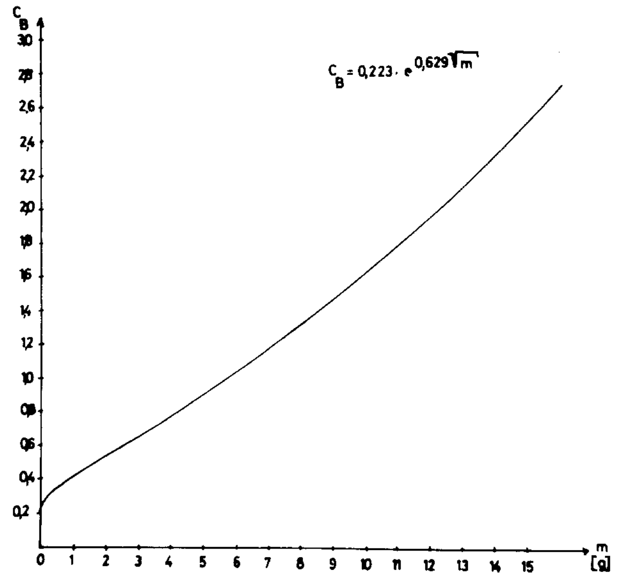

Fig. 10. Ballistic coefficient C_B, depending on the mass m of the projectile

The comparison with formula (15) results in

$$(22) \quad c = \frac{2}{\rho \cdot C_B}$$

ρ meaning the density of the medium. For the human body, ρ can be set = 1 (see Fig. 9).

$$(23) \quad c = \frac{2}{C_B} \quad \text{or (23a) } C_B = \frac{2}{c_i} \quad \text{with } i = 1, 2, \ldots 8.$$

For the eight test projectiles, the following C_B-values were obtained:

C_{B1} = .85	C_{B5} = 1.23
C_{B2} = .99	C_{B6} = 1.07
C_{B3} = 2.41	C_{B7} = 2.94
C_{B4} = 1.17	C_{B8} = .40

As all the c-values depend on the mass, the same is consequently true for the C_B-values.

For C_B, this equation can be applied:

$$C_B = \frac{2}{c} = \frac{2}{8.979 \cdot e^{-.629\sqrt{m}}} \quad \text{or}$$

(24) $C_B = .223 \cdot e^{.629\sqrt{m}}$

This proves the dependence of the ballistic coefficient C_B on the mass of the projectile (see Fig. 10).

2. Conversion Factor

For the comparison of skin + Mipoplast® to skin + muscle tissue.

Our results were mainly obtained by experiments with the mixed medium skin + Mipoplast®; therefore, the ballistic behaviour of projectiles, penetrating skin + muscle tissue, still remains to be described. The variation of the penetrated medium can only have an effect on factor c in formula (15). Instead of altering factor c, which depends on the mass according to formula (16), it turned out to be clearer to retain it as constant and to initiate another factor μ, solely depending on the medium.

Sufficiently numerous experiments with skin + muscle tissue (corpses) revealed a value of μ = 1.2 (exactly 1.19) by a direct comparison for the same type of projectile, i. e. the depth of penetration into skin + muscle tissue is 1.2 times greater than the depth of penetration into skin + Mipoplast®. Applying formula (15) not to Mipoplast®, but to muscle tissue, it has to be multiplied by μ= 1.2.

Besides, a numerical comparison to Mattoo's experiments with corpses (1974) exactly revealed the value μ = 1.2. Thus this final formula for the depth of penetration into the human body can be gained:

(25) $s = 1.2. \cdot c \cdot \frac{m}{A} \cdot \ln \frac{v}{v_{cr}}$,

v_{cr} calculated by formula (10), and c by formula (16).

Conclusion

Even though with certain reservations, the Federal Gun Control Act (WaffG), according to the promulgation of March 8, 1976, (BGBl. I p. 432) is still based in the principle that firearms with projectiles of a kinetic energy of less than 7.5 J are less dangerous and, therefore, are subject to certain waivers and exemptions (e. g. Para 32, Sect. 2, No. 1 WaffG). Primarily, the Act refers to energy in terms of its previously conceived findings, when privileging certain facts (e. g. Para 22, Sect. 2, No. 1; 32, Sect. 2, No. 1; 45, Sect. 6, No. 2a WaffG; Paras 1, Sect. 1, No. 1; 2, Sect. 4, No. 3a; 5, Sect. 1 of the First Weapon Regulation WaffV).

Sellier (1976) extensively investigated the origin of the legal limit of 7.5 J. Among other things he confirmed that the legally established critical enery is not at all a harmless or an undangerous limit, which it actually ought to be; see Tausch, Sattler, Wehrfritz, Wehrfritz, Wagner (1976) as well.

Starting from formula (12),

$$E_{cr} = \frac{m}{2000} \cdot (162.1 \cdot e^{-.38\sqrt{m}})^2$$

and considering the graphical representation of this function (see Fig. 7), an interesting result can be achieved: The critical energy of 7.5 J corresponds to a projectile of a mass of m = 1.4 g. Restricting the calculation to lead bullets, the critical energy (formula (12)) can be represented as a function of the spherical diameter:

$$(26) \quad E_{cr} = 77.78 \cdot d^3 \cdot e^{-1.85 \cdot d^{3/2}}$$

A lead bullet of 1.4 g has a diameter of 6.2 mm. It is just in a position to penetrate human skin at an energy of 7.5 J. All lead bullets with a diameter of less than 6.2 mm do absolutely penetrate the skin at 7.5 J.

Numerous weapons with a smaller caliber are commercially available without any restrictions (Para 2, Sect. 4 of the First Weapon Regulation, WaffV); their corresponding projectiles in a caliber of normally 4.5 mm can reach a kinetic energy of up to 7.5 J. Those weapons – BB guns, operated by air-pressure, spring or a CO_2-cartridge – are tolerated by Para 21 WaffG. The commercially available projectiles have a weight of approximately .53 g. Such a projectile of .53 g only requires an energy of 4.0 J for the penetration of human skin, according to formula (12).

In reference to Tausch, Sattler, Wehrfritz, Wehrfritz, Wagner (1976), even weapons with a kinetic energy of 2.2 J cannot be regarded as "undangerous" in certain cases. Even if one wants to maintain the energy limit of 7.5 J for the differentiation between exempted weapons and those totally covered by the Gun Control Act, the legislature would still have to establish a minimum mass for the projectiles. Considering the results obtained, the limitation of the kinetic energy of 7.5 J alone does not guarantee the "harmlessness"" the present law is based on.

A projectile mass of 1.4 g and a kinetic energy of 7.5 J can absolutely reach a level of danger, which up to now has not been taken into account by the legislature. Those circumstances should be considered when licensing weapons according to Paras 21 and 25 WaffG as well as when prohibiting weapons according to Para 37 WaffG and Para 8, Sect. 1, No. 1 of the First Weapon Regulation (WaffV).

In future, criminology and legal medicine will have to take into consideration, whether projectiles of a very small mass play a decisive role in certain cases of obscure deaths. Such projectiles could reach their goal with an absolutely lethal effect by means of an unrestricted air-pressure-operated gun, nearly without any visible injuries.

Acknowledgements. We want to express our gratitude for support granted by the Federal Criminal Investigation Office in Wiesbaden, by the State Criminal Investigation Office in Koblenz, and by the Regional Government of Rheinhessen-Pfalz in Neustadt/Weinstraße in the conduct of this study

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Received April 19, 1978