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PENETRATION EXPERIMENTS OF AIR RIFLE PROJECTILES WITH CALIBER 6.35 MM AND DIFFERENT NOSE SHAPES IMPACTING 10% GELATINE

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Abstract. *Air rifles in caliber 6.35 mm and more than 10 J in kinetic energy at impact can have a significant effect on soft tissues of animals and humans. To study the effect, experimental penetration studies have been conducted by using test specimens made of 10% gelatine substitute. The 10% gelatine used in the tests fulfilled the FBI standard protocol for penetration depth of 4.5 mm BB steel sphere impacting with 180 m/s. The deceleration, penetration depth, and dynamic penetration cavity size for the projectiles with different nose shapes impacting gelatine 10% have been studied. The impact velocity was measured by using a chronograph and the initial kinetic energy before impact of the projectiles was up to 84 J (330 m/s). The deceleration and dynamic cavity size was studied by using high-speed camera with 10000 frames per second. Final penetration depth was manually measured. The nose and projectile shape influenced the dynamic cavity size and final penetration depth in the gelatine to a large extent. All experimental results, including high speed films and python simulation code of gelatine penetration, are publicly available, see [1].*

1 INTRODUCTION

1.1 Background

To improve civil defence shelters, it is important to understand the effect of how splinter and debris of metals and concrete with high kinetic energy generated from explosions and how these would affect human body and its soft tissues during impact and penetration. To derive physical simulation models to include the effects, it is necessary to understand the physics of rapid penetration into soft body tissue. This paper has been conducted to broaden the civil defence knowledge and to be able to simulate the effects in physical experiments of penetration into soft tissue with small calibre air rifle, 4.5 mm and 6.35 mm. Here, the soft tissue is simulated by using 10% gelatine blocks. In simulation of hydrogels prepared from water solutions containing 10-20 mass % gelatine is generally acknowledged as muscle tissue simulants in terminal ballistic research [2]. As gelatine is a natural component of meat, made by the hydrolysis of collagen during processing and cooking. In [3] it is shown that extruded gelatine of microfibers mimics structural and biochemical characteristics of natural muscle tissues but is lacking surface layer which represents the effect of human skin and the density of bones. Gelatine is used to visualize both temporary and permanent impacts of which are conceived as providing a reasonable approximation to wounding in humans, as gelatines are used in both fatality and survivability studies, also comparison of ammunition effects [4].

1.2 Definitions

The following definitions in *italics* are used in this paper:

10% gelatine block is a water-based solution containing 10% gelatine, developed according to Appendix 1.

Depth of Penetration (DOP) is the final penetration distance at rest that the penetrator travelled from entrance point to the tip of the penetrator, permanent measured from entry point in gelatine to tip of penetrator.

10% gelatine block fulfilling the FBI standard protocol is a block which have been initially shot with 4.5 mm steel sphere with impact velocity of 180±3 m/s having a DOP of 8.5±1 cm, see [6].

Dynamic Cavity Diameter (DCD) is the maximum expanded diameter observed in the 10% gelatine block with high-speed filming during the penetration process.

H&N 6.35 mm type of penetrators used in this terminal ballistic study are defined in Table 1. The penetration results from *Trophy, Extreme, Hunter,* and *Spitzkugel* are presented and discussed in this paper. The penetration results from *Slug* and *Hornet* are omitted due to paper size, results for these penetrators are found in [1].

(a)		*Trophy*: H&N Trophy 6.35 mm Trophy – Baseline penetrator Nose shape: spherical Material type: lead mass: 1.3 g
(b)		*Extreme*: H&N Baracuda Hunter Extreme 6.35 mm Nose shape: deep cross-shaped hollow tip Material type: lead mass: 1.83 g mass increase compared to Trophy: 40.8 %
(c)		*Hunter*: H&N Baracuda Hunter 6.35 mm Nose shape: smooth with deep hollow point. Material type: lead mass: 1.78 g mass increase compared to Trophy: 36.9 %
(d)		*Spitzkugel:* H&N Spitzkugel 6.35 mm Nose shape: smooth cone shape with sharp tip. Material type: lead mass: 1.62 g mass increase compared to Trophy: 24.6 %
(e)		*Slug:* H&N Slug 6.35 mm Nose shape: smooth cone shape with deep hollow point. Material type: lead mass: 2.33 g mass increase compared to Trophy: 79.2 %
(f)		*Hornet:* H&N Hornet 6.35 mm Nose shape: Cone shape with smaller diameter metal tip cone. Material type: lead and tip of brass mass: 1.43 g mass increase compared to Trophy: 10.0 %

Table 1: Different H&N penetrator types are defined: *Trophy*, *Extreme*, *Hunter, Spitzkugel, Slug, and Hornet* in 6.35 mm calibre. Data and pictures from [5].

2 EXPERIMENTS

2.1 Material Specifications of used 10% gelatine block

The 10% gelatine blocks were manually mixed by using warm water and 100% gelatine powder a few days before the experiments presented in this paper, see Appendix I. The 100% gelatine powder used in the mixture is a commercially available product and is made from boiling the connective tissues, bones, and skins from cows.

2.2 Test Arrangements

The experiments were conducted near Uleåborg/Oulu, Finland, during the summer months of July and August 2021. The test arrangements for the penetration experiments of 10% gelatine is shown in Figure 1. The experiments were conducted on a wooden table. Figure 1 shows the air rifle positioning and model type, Crosman and Hatsan, for the two different calibres 4.5 mm BB steel ball and 6.35 mm that have been used. The projectile's impact velocity was measured with a chronograph. The 10% gelatine block of outer size 15 x 35,5 x 14,2 cm was fixated on a wooden block. The bottom surface of the wooden block had sandpaper attached for increased friction between wooden block and wooden table. The wooden block was also provided with a back stop to prohibit the gelatine to jump during the impact by the penetrator. The wooden block had a ruler mounted alongside below the gelatine block for digital measurements on films with the highspeed camera. The right side of the wooden table had natural day light. This is still not enough for the high-speed filming, see Figure 1 for camera positioning. The important flicker free LED lightning was added with a total of 720 W. The high-speed camera was set up to film a major part of the gelatine block with camera resolution 640x240 and 10 488 frames per second (FPS). The FPS speed was targeted to have enough film frames to capture the complete penetration process from impact the gelatine to standstill. Before and after each shot a photo was taken with mobile phone and the depth of penetration (DOP) was manually measured with a ruler after each shot.

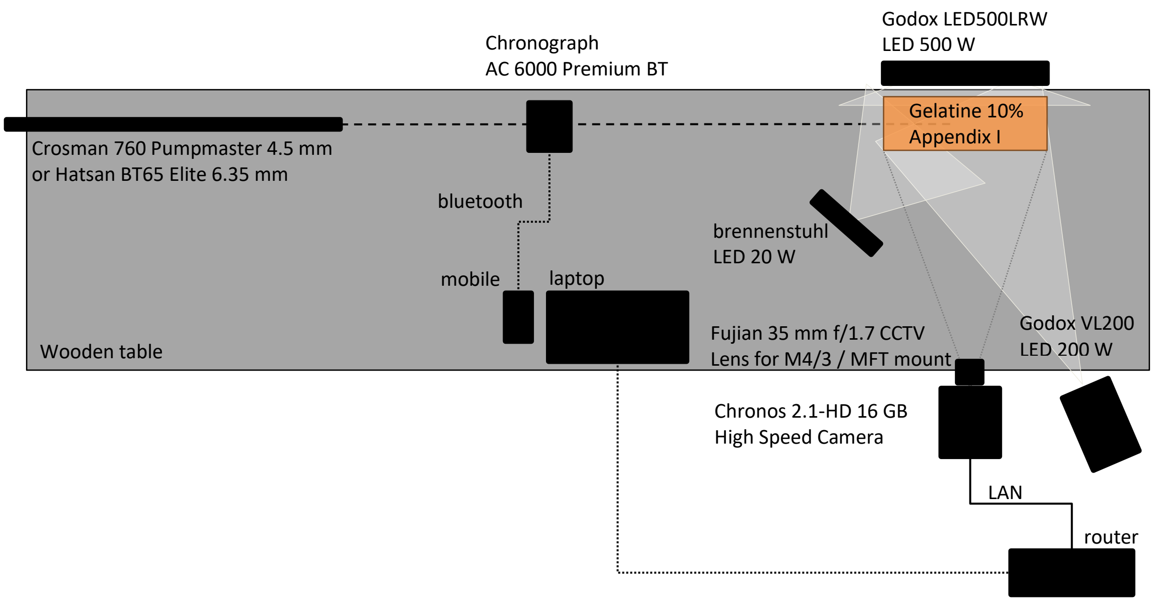


Figure 1: Principal sketch of test arrangement for 4.5 mm and 6.35 mm calibre gelatine 10% experiments.

2.3 Test series conducted

The test series conducted in these experiments are summarized in Table 2. There are two series in the experiments, the main series during the dates 2021-08-24 and 2021-08-28 and one pre-series during the dates 2021-07-19 and 2021-08-24. During the pre-series period, lot of experimental tuning was done. Everything from how to manufacture even quality of 10% gelatine blocks, to have enough lighting for the high-speed camera. In addition, it was elementary to find an adequate air rifle that can conduct the mandatory FBI protocol verification shot with a 4.5 mm BB steel ball 180 m/s with impact velocity. This was solved by using the Crosman 760 pumpmaster 4.5 mm BB, which also allows easy tuning of the impact velocity of the pellets by adjusting how many manual pumping actions are made before each shot. Different amount of pump actions such as: four, six, eight, 12 pumps, leads to 130, 160, 180, and 193 m/s, respectively, as impact velocity for 4.5 mm BB steel ball. The pre-series results will only be used as indication of manual measurement of DOP. The films are omitted from analysis due to no systematic check FBI standard protocol was conducted on these gelatine blocks. From the main series, the films are analysed and used for evaluating the time dependent DOP and the DCD.

Gelatine Block(GB)-date-nr	**nr of GB [-]**	**nr of FBI Prot. 4.5 mm [-]**	**nr of cal. 4.5 mm shots [-]**	**nr of cal. 6.35 mm shots**	**impact velocity range v_x [m/s]**	**nr of high speed films [-]**	**projectile type**
GB210828nr3	1	1			182	1	ASG BB 4.5 mm
			16		67-318	14	Gamo Hunter impact 4.5 mm
GB210828nr2	1	1			177	1	ASG BB 4.5 mm
				8	294-300	6	Barracuda Hunter 6.35 mm
GB210828	1	1			180	1	ASG BB 4.5 mm
				7	294-299	5	Barracuda Extreme 6.35 mm
GB210827nr4	1	1			178	1	ASG BB 4.5 mm
				6	255-298	5	Spitzkugel 6.35 mm
GB210827nr3	1	1			178	1	ASG BB 4.5 mm
				11	211-323	4	Trophy 6.35 mm
GB210827nr2	1	1			180	1	ASG BB 4.5 mm
			11		134-194	4	BB ASG 4.5 mm
GB210827	1	1			182	1	ASG BB 4.5 mm
			11		133-183	6	BB ASG 4.5 mm
GB210825nr3	1	1			183		ASG BB 4.5 mm
				10	211-262	4	Slug 6.35 mm
GB210825nr2	1	2			175-177		ASG BB 4.5 mm
				15	281-322	8	Slug 6.35 mm
GB210825	1	0					-
				12	311-336	9	Trophy 6.35 mm
Sum	**10**	**10**	**38**	**69**		**72**	
Total shots				**117**			
Pre series							
GB210824nr3	1	0		4	97-189	2	Trophy 6.35 mm
				4	291-298		Hornet 6.35 mm
GB210824nr2	1	0		8	256-333	4	Trophy 6.35 mm

Gelatine Block(GB)-date-nr	nr of GB [-]	nr of FBI Prot. 4.5 mm [-]	nr of cal. 4.5 mm shots [-]	nr of cal. 6.35 mm shots	impact velocity range v_x [m/s]	nr of high speed films [-]	projectile type
GB210824	1	0		13	220-270	4	Trophy 6.35 mm
GB210823nr2	1	0		4	385-295	4	Trophy 6.35 mm
				3	235-246		Grizzly 6.35 mm
GB210823	1	0	13		186-397	3	UMAREX
			7		254-293	2	gamo 4.5mm hunter
GB210821	1	1			185	3	UMAREX
			2	3	254-293	2	UMAREX
GB210819	1		7		136-146		UMAREX
GB210729nr2	1			7	307-327		Trophy 6.35 mm
GB210729nr1	1			4	216-231		Trophy 6.35 mm
GB210719	1			12	172-331		Trophy 6.35 mm
Sum	**10**	**1**	**29**	**62**		**24**	
Total shots				**92**			
	nr of total GB [-]			**nr of total shots [-]**		**nr of high speed films [-]**	
Total	**20**			**209**		**96**	

Table 2: Test series conducted. Dates GB210825 to GB210828 are the main series, dates GB210719 to GB210824 are the pre-series, where tuning of experiments were conducted.

3 EXPERIMENTAL RESULTS

The experiments are summarised in Section 3.1 and Section 3.2 shows the DOP and high-speed film experimental results of projectile penetration and estimations of the maximum DCD. All experimental results including high speed films are publicly available, see [1].

3.1 Experimental summary table

The H&N Trophy 6.35 mm terminal ballistics experiments in 10% gelatine are summarized in Table 3. The maximum impact velocity was 327.5 m/s with maximum DOP of 26.0 cm. All DOPs were measured manually with a ruler by positioning the ruler at entry point height in the gelatine to tip of the penetrator at rest. The minimum impact velocity was 211.3 m/s with a DOP of 21.8 cm. The average impact velocity of the 11 shots in the GB210827nr3 series was 266 m/s and the average DOP 22.7 cm. The Trophy penetrators were intact in shape, i.e. no signs of expansion after the shots as seen in Figure 2 (shot 2). In addition, the Trophy penetrator had in general straight trajectory with no tumbling or rotations while penetrating the gelatine. The Photos are given as time stamps which is also used in the file name of the photos in [1].

Shot nr [nr]	Impact velocity [m/s]	DOP [cm]	Film / Photo [id / time]	Penetrator [name]
1	180.0	9.5	GB210827nr3-1/18:43	ASG BB 4.5 mm
2	273.4	21.5	GB210827nr3-2/18:53	Trophy 6.35 mm
3	264.7	21.9	GB210827nr3-3/19:03	Trophy 6.35 mm
4	257.3	21.8	GB210827nr3-4/19:09	Trophy 6.35 mm
5	257.5	21.6	- / 19:14	Trophy 6.35 mm
6	256.3	21.8	- / -	Trophy 6.35 mm
7	221.9	21.2	GB210827nr3-7 /19:28	Trophy 6.35 mm
8	216.1	21.5	GB210827nr3-8 /19:33	Trophy 6.35 mm
9	211.3	21.8	GB210827nr3-9 /19:38	Trophy 6.35 mm
10	327.5	26.0	GB210827nr3-10 /19:50	Trophy 6.35 mm
11	322.6	25.5	- / -	Trophy 6.35 mm
12	320.5	25.4	- / 20:00	Trophy 6.35 mm

Table 3: H&N Trophy 6.35 mm calibre terminal ballistics on 10% gelatine, test series GB210827nr3. Hyphen means missing film or photo.

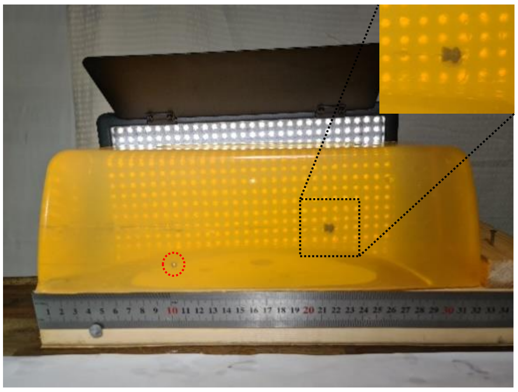


Figure 2: Terminal ballistic photo of GB210827nr3 after shot 2 at time 18:53 for H&N Trophy 6.35 mm with 273.4 m/s impact velocity into gelatine 10% and DOP 21.5 cm. The dotted circle marking the spherical metal pellet 4.5 mm is the FBI protocol shot 1 in GB210827nr3 series. Zoomed in picture shows shot 2.

The H&N Baracuda Hunter Extreme 6.35 mm terminal ballistics experiments in 10% gelatine are summarized in Table 4. The maximum impact velocity was 298.9 m/s with maximum penetration depth of 13.6 cm. The minimum impact velocity was 294.1 m/s with 15.0 cm DOP. The average impact velocity of the 7 shots in GB210828 series was 297 m/s and the average DOP 14.5 cm. The Extreme Penetrator expands heavily and flattens the length of the penetrator and widens the diameter during the penetration of the gelatine, see Figure 3. It also shows that the Extreme penetrator can also tumble during the penetration process, see Figure 3 the lower penetrator is shot 2 with at least 90-degree rotation as final heading. When comparing the Trophy and the Extreme penetrator, it is evident that even though that the impact velocities are slightly higher for the Extreme shots and that the mass of the Extreme is 41 % higher than Trophy, yet, the DOP were in average 36% lower for the shots with the Extreme penetrator compared to the shots with the Trophy penetrator, compare Table 2 with Table 3.

Shot nr [nr]	Impact velocity [m/s]	DOP [cm]	Film / Photo [id / time]	Penetrator [name]
1	180.1	**9.3**	GB210828-1/10:26	ASG BB 4.5 mm
2	297.8	**13.5**	GB210828-2/10:51	Extreme 6.35 mm
3	294.8	**14.5**	GB210828-3/11:00	Extreme 6.35 mm
4	298.9	**13.6**	-/11:04	Extreme 6.35 mm
5	298.6	**14.2**	GB210828-5/11:08	Extreme 6.35 mm
6	298.3	**14.5**	GB210828-6/11:27	Extreme 6.35 mm
7	297.0	**15.9**	- / -	Extreme 6.35 mm
8	294.1	**15.0**	- / 11:34	Extreme 6.35 mm

Table 4: H&N Extreme Baracuda 6.35 mm calibre terminal ballistics on 10% gelatine, test series GB210828.

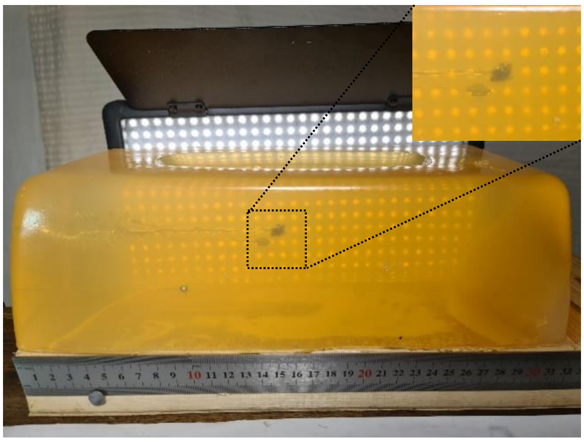


Figure 3: Terminal ballistic photo of GB210828 after shot 2 and shot 3 at time 11:00 for H&N Baracuda Hunter Extreme 6.35 mm with shot 2 and shot 3 having 297.8 and 294.8 m/s in impact velocity resulting in DOP 13.5 and 14.5 cm, respectively. Zoomed in picture shows shot 2 and shot 3.

The H&N Baracuda Hunter 6.35 mm terminal ballistics experiments in 10% gelatine are summarized in Table 5. The second shot in the series had a maximum impact velocity of 300.2 m/s which was the highest in the whole series, it had a DOP of 12.5 cm. The penetrator expanded and was intact and with at least 90-degree rotated heading in final position. Shot 3, 4, 5, 6, and 9 had all that the penetrator split in two parts a minor centre part and a major ring part. These had different final DOP shot 3 had 19.0 cm for minor centre part and 16.5 cm for major ring part, see Figure 4. These major ring parts DOP of each of the penetrators are given in Table 4 as values in parenthesis () for DOP. The shot 7 and 8 was a double loaded shot, i.e. two penetrators leaving barrel at the same time, these seem to be without separation.

Shot nr [nr]	Impact velocity [m/s]	DOP [cm]	Film / Photo [id / time]	Penetrator [name]
1	177.0	9.5	GB210828nr2-1/11:53	ASG BB 4.5 mm
2	300.2	12.5	GB210828nr2-2/12:03	Hunter 6.35 mm
3	299.7	19.0 (16.5)	GB210828nr2-3/12:06	Hunter 6.35 mm
4	298.9	18.0 (17.0)	GB210828nr2-4/12:18	Hunter 6.35 mm
5	298.6	19.5 (19.0)	GB210828nr2-5/12:24	Hunter 6.35 mm
6	298.3	19.5 (16.5)	- / -	Hunter 6.35 mm
7	297.0	15.9	*Common with below*	Hunter 6.35 mm
8	294.1	23.0	GB210828nr2-8/12:37	Hunter 6.35 mm
9	298.4	21.0 (19.0)	GB210828nr2-9/12:46	Hunter 6.35 mm

Table 5: H&N Baracuda Hunter 6.35 mm calibre terminal ballistics on 10% gelatine, test series GB210828nr2. Some of shots have two Depth of Penetration values one plain representing centre part DOP and with paranthesis “(xx.x)” for the major ring part DOP.

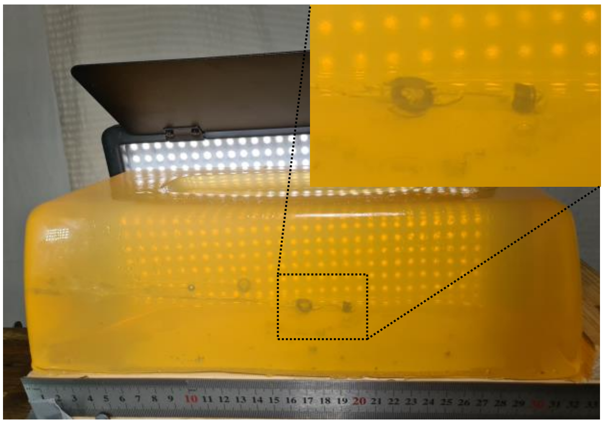


Figure 4: Terminal ballistic photo of GB210828nr2 after shot 2 and shot 3 at time 12:06 for H&N Baracuda Hunter 6.35 mm with shot 2 and shot 3 having 300.2 and 299.7 m/s in impact velocity resulting in DOP 12.5 and 19 (16.5) cm, respectively. Zoomed in picture shows shot 3 with the split penetrator in minor centre part and major ring part.

The H&N Spitzkugel 6.35 mm terminal ballistics experiments in 10% gelatine are summarized in Table 6. The second shot in the series had a maximum impact velocity of 297.6 m/s which was the highest in the whole series, it had a DOP of 25.5 cm. The average impact velocity of the six shots was 277.4 m/s with a DOP of 24.0 cm. Figure 5 shows a photo after shot 4. First shot is the FBI protocol shot with ASG BB 4.5 mm. It can be observed that all three thereafter following shots have straight trajectories with almost no rotation of the penetrator in the final DOP resting position.

Shot nr [nr]	Impact velocity [m/s]	DOP [cm]	Film / Photo [id / time]	Penetrator [name]
1	178.0	9.4	GB210827nr4-1/20:18	ASG BB 4.5 mm
2	297.6	25.5	GB210827nr4-2/20:22	Spitzkugel 6.35 mm
3	294.2	24.5	GB210827nr4-3/20:31	Spitzkugel 6.35 mm
4	292.2	24.8	GB210827nr4-4/20:34	Spitzkugel 6.35 mm
5	269.3	23.0	GB210827nr4-5/20:34	Spitzkugel 6.35 mm
6	255.2	22.9	- / -	Spitzkugel 6.35 mm
7	256.1	23.0	- / 20:49	Spitzkugel 6.35 mm

Table 6: H&N Baracuda Spitzkugel 6.35 mm calibre terminal ballistics on 10% gelatine, test series GB210827nr4.

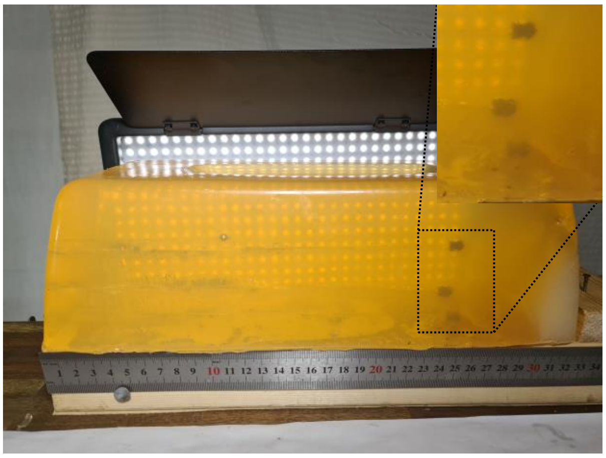
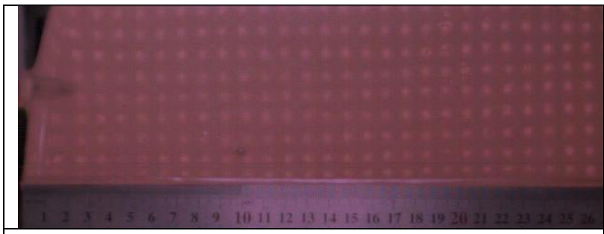
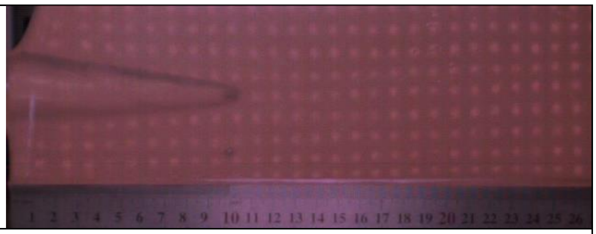
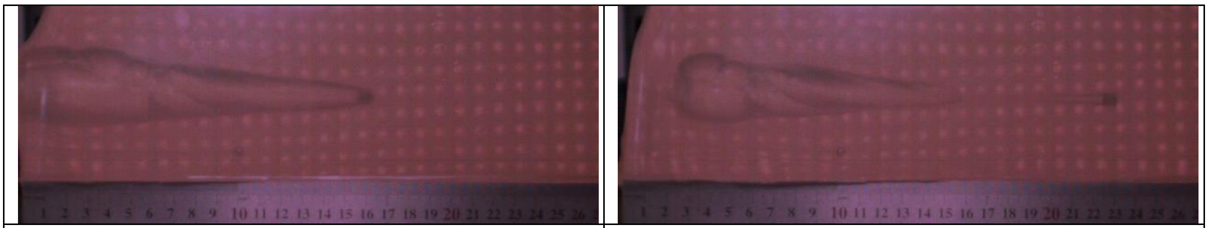


Figure 5: Terminal ballistic photo of GB210827nr4 after shots 2, 3, and 4 at time 20:31 for H&N Spitzkugel 6.35 mm with shot 2, 3, and 4 having 297.6, 294.2, and 292.2 m/s in impact velocity resulting in DOP 25.5, 24.5, and 24.8 cm, respectively. Zoomed in picture shows shot 2 (bottom), shot 3 (top), shot 4 (middle).

3.2 Penetration depth and High-speed camera results

The high-speed camera results were processed by using the VSDC Video Editor version 6.9.5.382, screen shots taken here are the original film frames (short keys ctrl+F12) without any colour, brightness, contrast, or sharpness adjustments. The high-speed camera results for the H&N Trophy 6.35 mm are shown in Figure 6 for series GB210927nr3, shot 2 at four different times. The impact velocity for this shot was 273.4 m/s with a DOP of 21 cm and the DCD was about 40 mm, see Table 2. The films show a quite straight trajectory and stable penetration process performed by the Trophy penetrator.

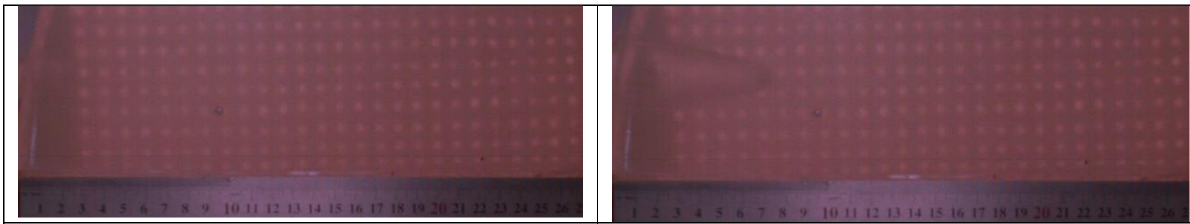
	
(a) time 00:00:40.950	(b) time 00:00:41.041



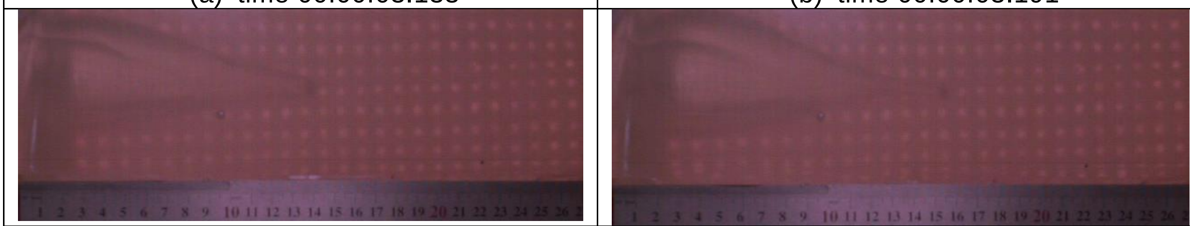
(c) time 00:00:41.133 | (d) time 00:00:41.433

Figure 6: Chronos 2.1 camera capturing 10 000 FPS of dynamic cavity and penetration at different times (a) to (d) for H&N Trophy 6.35 mm with 273.4 m/s impact velocity into gelatine 10%. Experiment number GB210827nr3-2. Metallic ruler below gelatine is in [cm].

For H&N Baracuda Hunter Extreme 6.35 mm in the test series GB210828, shot 2, the impact velocity was 297.8 m/s and resulted a DOP of 13.5 cm, see Table 4. In Figure 7 the dynamic cavity and penetration progress are shown. The DCD is about 6 cm when it has reached maximum expanded state. The filming for the H&N Baracuda Hunter Extreme 6.35 mm shows in all films the effect of controlled expansion of the penetrator, so called “Mushrooming”. The dynamic cavity is steadily expanding throughout the complete penetration process. This steady expanding process during Baracuda penetration is also seen in the result of significantly shorter DOP. The main cause for the shorter DOP distance is that the penetrated material absorbs the kinetic energy from penetrator in a shorter DOP due to the “perfect” flattening and widening of the penetrator without penetrator splitting or rotating too much during the penetration process.



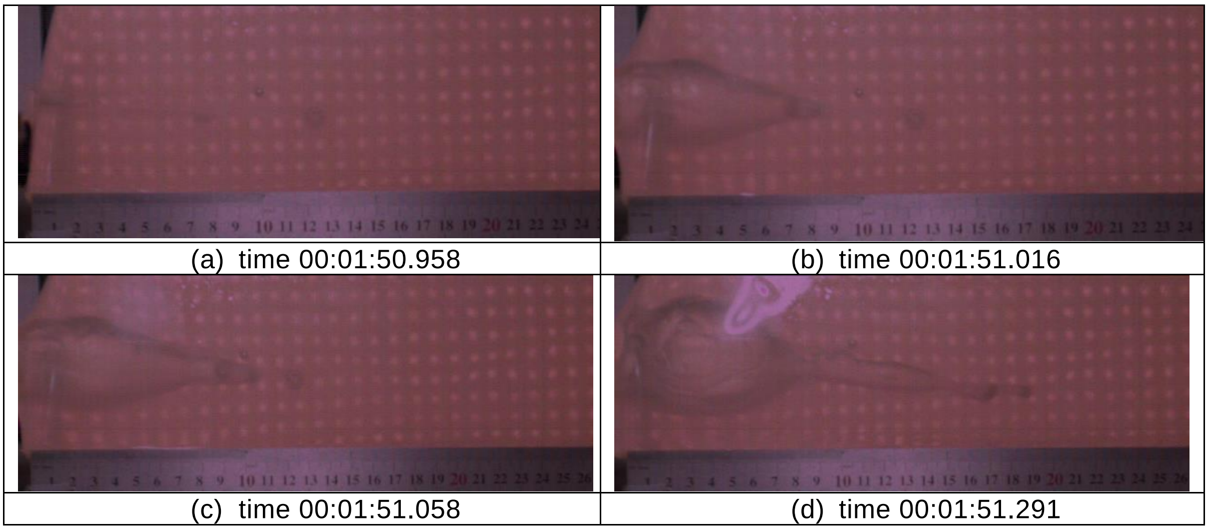
(a) time 00:00:03.133 | (b) time 00:00:03.191



(c) time 00:00:03.350 | (d) time 00:00:03.500

Figure 7: Chronos 2.1 camera capturing 10 000 FPS of dynamic cavity and penetration at different times (a) to (d) for H&N Baracuda Hunter Extreme 6.35 mm with 297.8 m/s impact velocity into gelatine 10%. Experiment number GB210828-2. Metallic ruler below gelatine is in [cm].

For H&N Baracuda Hunter in the series GB210828nr2, shot 3, the impact velocity was 299.7 m/s and resulted in a DOP of 19 cm, see Table 5. In Figure 8 the dynamic cavity and penetration progress are shown. The DCD is about 6 cm when it has reached maximum expanded state. The filming for the H&N Baracuda Hunter shows in most films that projectile breaks into two parts, and that the dynamic cavity expansion process is not as steady when compared to Extreme penetrator.

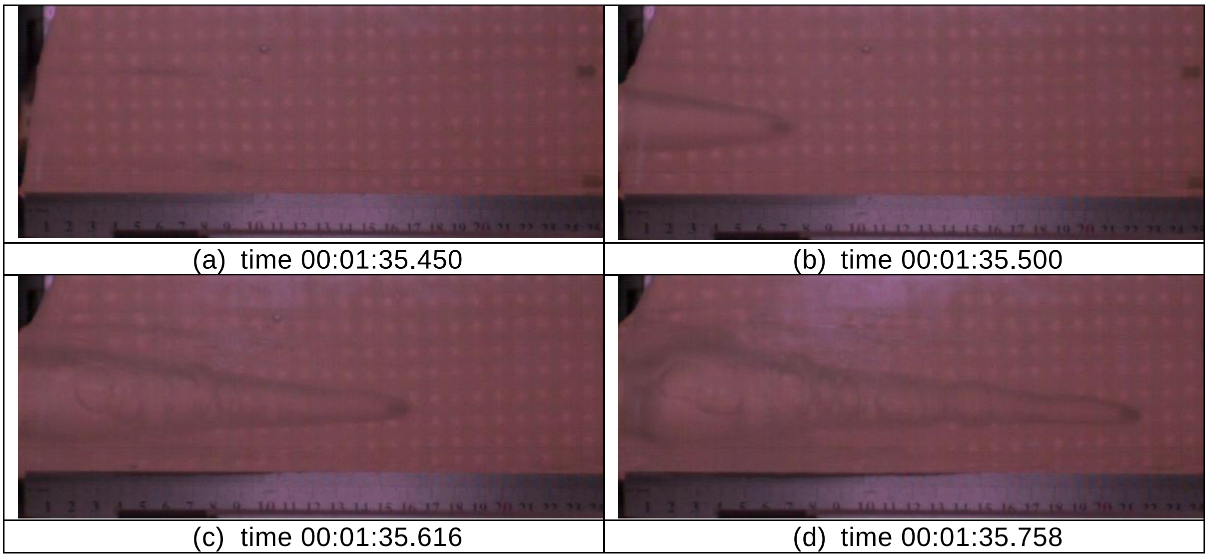


(a) time 00:01:50.958 | (b) time 00:01:51.016

(c) time 00:01:51.058 | (d) time 00:01:51.291

Figure 8: Chronos 2.1 camera capturing 10 000 FPS of dynamic cavity and penetration at different times (a) to (d) for H&N Baracuda Hunter 6.35 mm with 299.7 m/s impact velocity into gelatine 10%. Experiment number GB210828nr2-3. Metallic ruler below gelatine is in [cm].

The H&N Spitzkugel in the series GB210827nr4, shot 4, the impact velocity was 292.2 m/s and resulted in a DOP of 24.8 cm, see Table 6. In Figure 9 the dynamic cavity and penetration progress are shown. The DCD is about 4.4 cm when it has reached maximum expanded state. The expansion phase is steady and stable during the different shots.



(a) time 00:01:35.450 | (b) time 00:01:35.500

(c) time 00:01:35.616 | (d) time 00:01:35.758

Figure 9: Chronos 2.1 camera capturing 10 000 FPS of dynamic cavity and penetration at different times (a) to (d) for H&N Spitzkugel 6.35 mm with 292.2 m/s impact velocity into gelatine 10% with final DOP 24.8 cm. Experiment number GB210827nr4-3. Metallic ruler below gelatine is in [cm].

4 CONCLUSIONS

The experiments showed that the manually manufactured 10% gelatine blocks fulfilled the FBI protocol requirements of DOP range allowed. The experiments were able to visualize the penetration process into 10 % gelatine blocks for different penetrator shapes by using mainstream high-speed camera with a resolution of 640x240 pixels and minimum of 10000 FPS. The used high-speed camera captured the whole penetration process from impact to final DOP inside the gelatine block including dynamic cavity diameter. Important take away is to have enough flickering free LED lighting power to make films bright enough due to the high FPS rate. To conduct the FBI protocol verification of the 10% gelatine blocks it is essential to have an appropriate air rifle to adjust the impact speed close to 180 m/s for the required BB 4.5 mm steel sphere. In these experiments with 4.5 mm the Crosman 760 Pumpmaster was used which is an accurate and reliable solution which has been produced for over 40 years. The different shaped penetrators of 6.35 mm calibre with impact kinetic energy of up to 84 J was conducted successfully with Hatsan BT65 Elite 6.35 mm.

The different H&N penetrators in calibre 6.35 mm were analysed with impact velocity ranging from 211 to 328 m/s in impact speed. The penetrator weight varied from 1.3 g to 2.33 g, and the maximum kinetic impact energy varied between 70-84 Joules. The different shape of penetrators resulted in different DOP and DCD. The shortest DOP and largest DCD was received by the Extreme penetrator. The main cause was the stable mushrooming by flattening and widening of the penetrator during the penetration process which led to large and steady dynamic cavity in the 10% gelatine block.

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APPENDIX I – RECIPE FOR PRODUCING GELATINE 10%

Ingredients needed and the process is described for producing 5 litre gelatine 10% concentration are given in this appensix. Important notice is to use gloves that are water and heat resistant while processing the gel.

Ingredients

4.5 litre water (clear and drinkable)
500 gram Pure Gelatin (in experiments the producer Nyttoteket Sweden was used).
5 drops of cinnamon oil (1 drop per litre for gelatine clarity)

Process

- Heat the water up to +80 degrees Celsius, use digital thermometer to check temperature.
- Pour the water into dough mixer with bucket minimum capacity of five litre. Pour the gelatine powder slowly into the dough mixer while the mixer is running on even speed.
- Add 5 drops of cinnamon oil, let mixer run for five minutes and check that all gelatine powder has desolved into the heated water.

- Use suitable mold shapes for the intended penetration experiments, here molds of plastic material with lid and with outer size of 15 x 35,5 x 14,2 cm and total volume of five litre was used.
- Coat inside the mold with a cooking oil to help the release the gel when it is ready.
- Pour the warm gel into the mold, use duct tape to seal the lid and secure the mold for transport.
- Cool the mold in +2 degrees Celsius refrigrator for about 24-48 hours.
- Before use, check the temperature initial +2 degrees temperature with a digital food themometer that can penetrate the gelatine. Document each gelatine, water concentration, gel concentration, refrigrator cooling time and initial gelatine temperature.
- Check the produced gelatine 10% penetration qualities by using FBI standard protocol by manual measurement of the penetration depth. The FBI standard protocol requires maximum penetration depth of 8.5 ± 1 cm for a 4.5 mm BB steel sphere impacting with 180 ± 3 m/s. If Crosman 760 pumpmaster rifle used, the impact velocity of 180 m/s is achieved with approximately 8 pumps. Use at least one FBI protocol verification per mold.
- If the mold is not fulfilling the penetration requirements, try to adjust the gelatine water ratio and the cooling time.