WOUNDARY BALLISTICS OF BIOLOGICAL TISSUE'S PLASTIC DEFORMATION ON THE MODEL OF BALLISTIC PLASTILINE USING HOLLOW POINT AND SHAPE-STABLE BULLETS

Kostiantyn Gumeniuk[1], Igor Lurin[2], Ievgen Tsema[3], Yaroslav Susak[3], Oleksandr Mykhaylenko[4], Volodymyr Nehoduiko[5], Serhiy Krymchuk[4], Oleksandr Gryshchenko[4], Kostiantyn Lopatiuk[4], Myhailo Maksymenko[4], Dmytro Dubenko[4], Yegor Tsema[6]

[1]Ukrainian Military Medical Academy of Ministry of Defense of Ukraine, Ukraine, Kyiv
[2]National Academy of Medical Sciences of Ukraine, Ukraine, Kyiv
[3]Bogomolets National Medical University, Ukraine, Kyiv
[4]State Research Forensic Center Ministry of Internal Affairs of Ukraine, Ukraine, Kyiv
[5]Military Medical Clinical Center of the Northern Region, Ukraine, Kyiv
[6]Faculty of Cybersecurity, Computer and Software Engineering of National Aviation University, Kyiv

Correspond author:
Ievgen Tsema, MD, professor, Department of Urgent and Vascular Surgery, Bogomolets National Medical University, Kyiv, Ukraine, Email: hemorrhoid@ukr.net

Abstract

Introduction. Modern military conflicts make many challenges for military surgeons associated with the use of new types of weapons – hollow point bullets. The solution to this problem, firstly, depends on studying the characteristics of the terminal ballistics of such ammunition and comparing the data obtained with the characteristics of traditional weapon.

The aim of the work is to conduct experimental modeling of the wound canal and residual wound cavity, which is formed due to plastic deformation from hollow point and non-hollow point bullets.

Materials and methods. The studies were carried out on 40 blocks of ballistic plasticine, in each of which one shot was fired from an AKS-74 assault rifle and a ZBROYAR Z-10 carbine. Depending on the type of ammunition, the blocks of ballistic plasticine were divided into 4 groups: Group 1 – 10 blocks into which shots were made with 5.45 mm non-hollow point military cartridges with "PS" bullets with a steel core "7N6"; Group 2 (10 blocks) – 5.45x39 mm cartridges with "V-Max" hollow point bullets; Group 3 (10 blocks) – with cartridges 7.62x39 mm; Group 4 (10 blocks) – cartridges 7.62x39 mm with hollow point bullets of the "SP" type.

Results and discussion. Only for a 5.45 mm military cartridge with "PS" bullets, both inlet and outlet bullet holes were detected in all 10 observations. When using non-hollow point bullets, the outer area of the bullet inlet correlates with the caliber of the projectile (1.6 times larger when using 7.62 mm bullets). For hollow point bullets, the caliber of the projectile does not significantly affect the area of the inlet ($P < 0.05$). The expansive properties of the bullet significantly increase the area of the bullet hole by 14.87-31.2 times compared to non-hollow point ammunition. Increasing the caliber of the non-hollow point bullet leads to a significant increase in the area of the sagittal section of the residual wound cavity in 1.59-2.03 times; whereas the expansive properties of the bullet do not significantly affect either the perimeter or the area of the sagittal section of the residual wound cavity. For non-hollow point bullets, the volume of the residual wound cavity is more correlated with the caliber of the bullet (increases by 3.36 times); whereas for an hollow point bullet, its caliber has a smaller effect on the volume of the residual cavity (increases by 1.37 times). The expansive properties of the bullet affect the volume of the residual wound cavity in two ways: for 5.45 mm bullets the residual wound cavity increases 1.49 times, for 7.62 mm bullets it decreases 1.65 times. The use of hollow point bullets of 7.62 mm leads to greater collateral damage (zone of secondary necrosis, molecular shock) due to the scattering of the kinetic energy of the bullet to the elastic deformation of near-woundary tissues compared to non-hollow point analogues. The use of 5.45 mm expansive bullets leads to the formation of a larger volume of irreversible damage due to plastic deformation compared to non-hollow point analogues.

Conclusions. The resulting model of plastic deformation of soft tissues, depending on the type of modern small arms, showed the dependence of the spatial configuration of the

inlet bullet hole, residual wound cavity and deformation and fragmentation of the bullet on the caliber of the cartridge and its expansive properties.

Key words: **terminal ballistics; wound ballistics; gunshot wound; wound canal; hollow point bullets; plastic deformation; residual wound cavity.**

Introduction

Simulation of a gunshot wound canal is the most important stage in the study of the mechanism of formation of gunshot wounds and is one of the main tasks of the study of wound ballistics [1-3]. Local military conflicts of recent decades around the world indicate that the use of modern firearms and ammunition has radically changed the nature of the received injuries and the structure of sanitary losses. The use of new types of weapons in the course of modern combat conflicts has led to an increase in the number of multiple, conjoined and combined wounds [4-7]. Modern gunshot wounds have morpho-functional changes and are characterized by severity, multiple, combined and combined injuries [4-6]. The traumatic effects of gunshot injuries in humans cannot be verified in vivo, so reliable tissue simulators must be used. The greatest recognition among imitators was received by 10% and 20% aqueous solutions of gelatin in the form of a gel, glycerin soap and ballistic plasticine [3, 8-11]. Research and study of all elements of the wound channel allows to study the features of the formation of the wound canal [12-14]. Consequently, the need for a deeper study of these objects of research concerns not only forensic science and forensic medical examination, but also intersects with surgical science in the aspect of studying modern gunshot wounds received in local military conflicts and in civil clashes. In the available literature, fundamental experimental studies on wound ballistics of plastic deformation of soft tissues with modeling of the residual wound cavity formed by bullets with expansive properties have not been found.

The aim of this work is to conduct experimental modeling of the wound canal and residual wound cavity, which is formed due to plastic deformation from hollow point and non-hollow point bullets.

Material and methods. The experimental study was carried out on the basis of the shooting gallery of the Kyiv scientific research expert and forensic center of the Ministry of internal affairs of Ukraine with the participation of specialists from the State scientific research expert and forensic center of the Ministry of internal affairs of Ukraine. A special certified ballistic plasticine (ROMA PLASTILINA No. 1, Ballistic Testing Backing Material,

USA, Fig. 1) was used as a ballistic material as a simulator of the component of plastic deformation of biological tissues.

Figure 1. Block of Ballistic Testing Backing Material prepared for shooting (USA)

To achieve the goal of the research, ballistic studies were carried out using 40 blocks of parallelepiped shaped ballistic plasticine (40.0x24.0x28.0 cm), each of which was fired one shot from assault rifle AKS-74 (Fig. 2) and a ZBROYAR Z-10 carbine with an optical sight (Fig. 3), from a distance of 25 m.

Figure 2. Assault rifle AKS-74

Figure 3. ZBROYAR Z-10 carbine

The experiments were carried out under normal environmental conditions (temperature 25 ℃, relative humidity 72%, atmospheric pressure 738 mm Hg). The blocks of ballistic plasticine were heated up to 30 ℃ before the shot. Depending on the type of ammunition that was used for experimental modeling of the plastic deformation of biological tissues, the blocks of ballistic plasticine were divided into 4 groups: Group 1 – 10 blocks into which shots were made with non- hollow point military cartridges of 5.45 mm with "PS" bullets with a «7H6» steel core; Group 2 – 10 blocks into which shots were fired using cartridges 5.45x39 mm equipped with hollow point bullets of the "V-Max" type; Group 3 – 10 blocks, which were fired at with non-hollow point cartridges 7.62x39 mm; Group 4 – 10

blocks, in which shots were made by cartridges 7.62x39 mm equipped with hollow point bullets of the "SP" type (Fig. 4). Thus, totally 40 shots were fired – 10 shots with each type of bullet.

Figure 4. Appearance of cartridges that were used in the experimental study: 1 - cartridges 5.45x39 mm equipped with hollow point bullets of the "V-Max" type (group 2 of blocks), 2 - military cartridges 5.45 mm with bullets "PS" with a "7N6 "steel core (Group 1), 3 - cartridges 7.62x39 mm (group 3), 4 - cartridges 7.62x39 mm equipped with hollow point bullets of the "SP " type (group 4)

After the shots, a planimetric study of the bullet hole configuration was carried out: the perimeter and area of the bullet hole were estimated, and the coefficient of bursting action of the projectile (the ratio of the wound hole perimeter to its area) was calculated. Planimetric coefficients were calculated programmatically using the software product "ImageJ", developed on the basis of free access at the link https: //imagej.nih.gov/ij/. Using computer analysis, the following planimetric parameters were calculated (see Fig. 5):

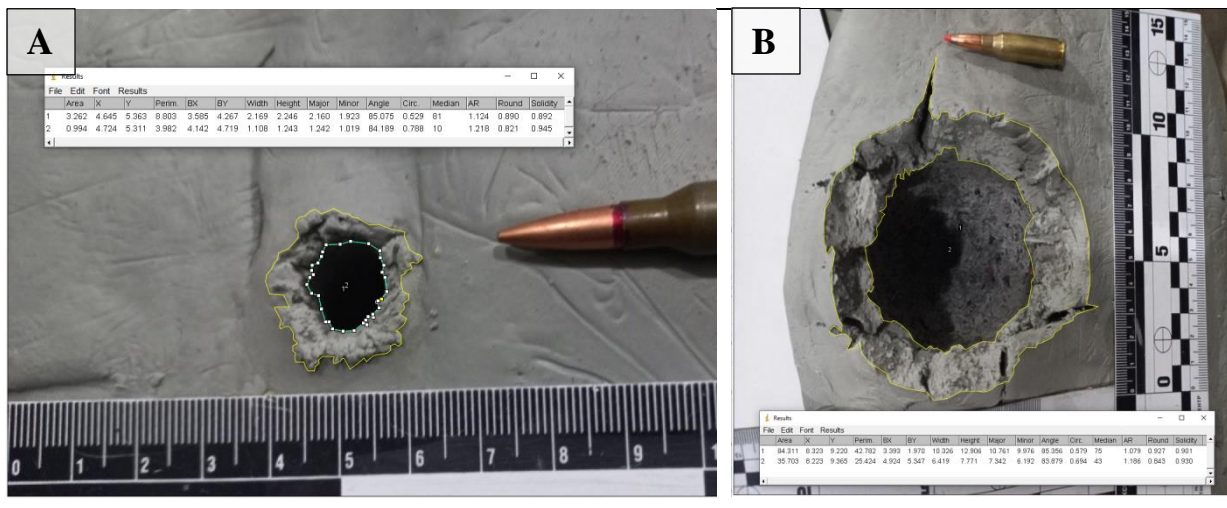Figure 5. Planimetric coefficients were calculated programmatically using the software product «ImageJ», National Institutes of Health by an employee of the Federal Government (Bethesda, Maryland, USA). Area 1 – outer area of gunshot opening (cm^2), Area 2 – inner area of gunshot opening (cm^2), Perim. 1 – outer perimeter of gunshot opening (cm), Perim. 2 – inner perimeter of gunshot opening (cm)

- ✓ outer perimeter of gunshot opening;
- ✓ inner perimeter of gunshot opening;
- ✓ outer area of gunshot opening;
- ✓ inner area of gunshot opening;
- ✓ perimeter area/ratio – was calculated as the ratio of the perimeter of the bullet hole to its area.

After completion of the planimetric measurements of the ballistic plasticine block obtained after the shot, the liquid plastic "Silicone Polysystem" (Rubber Silicone Liquid, Germany) was poured into the inlet, which has a sealing property taking a corresponding shape inside the ballistic plasticine (Fig. 6).
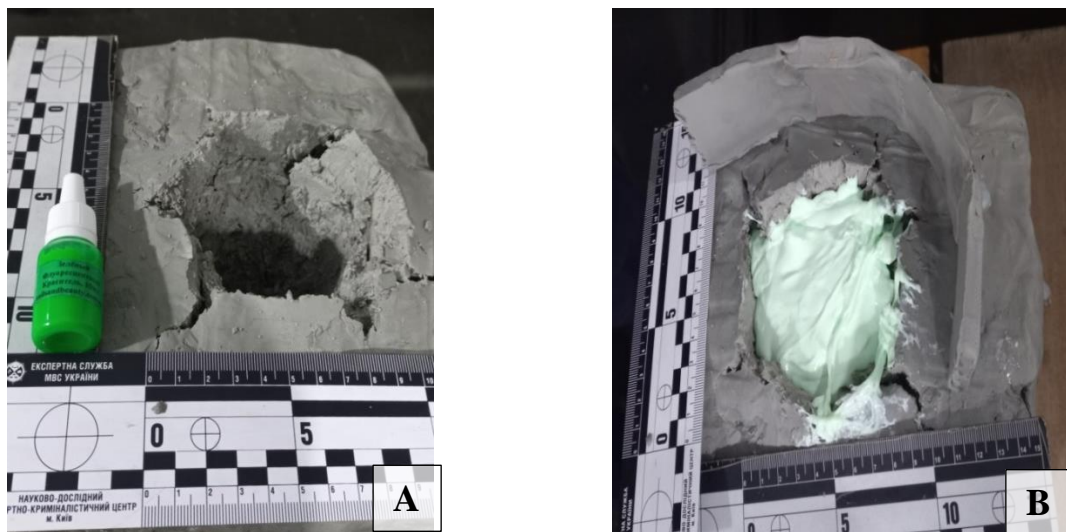
Figure 6. Bullet inlet hole (A) and molding with liquid plastic (B)

After 30 minutes, the liquid plastic becomes dense after pouring. The composition of liquid plastic includes two components: A and B, which were mixed before pouring in a 1:1 ratio, thoroughly mixed by hand for 40 seconds until a homogeneous mass was obtained, at a temperature of 22-25 ° C, after which the solution was ready for use. For a clearer visualization of the expansive characteristics of bullets, a dye of different colors was added to the plastic mass: green – for hollow point bullets; red – for non-hollow point bullets (Fig. 7).

Figure 7. Bullet inlet (A) and molding with liquid plastic (B)
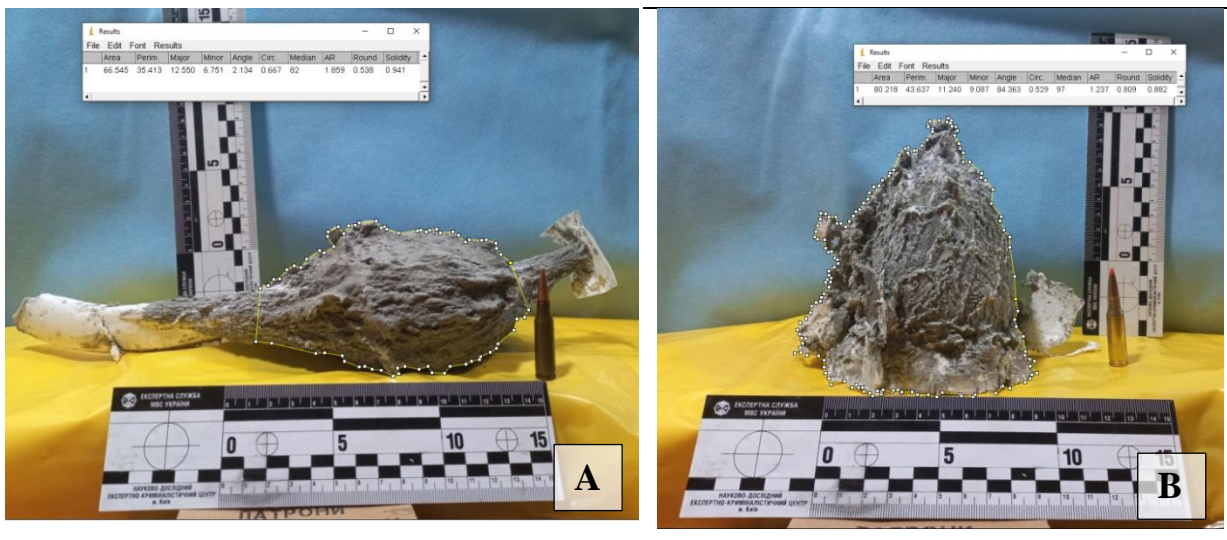
Figure 8. Measurement of the indicators of the residual wound cavity (A – 5.45 mm "PS", B – 5.45 mm "V-max") calculated after fil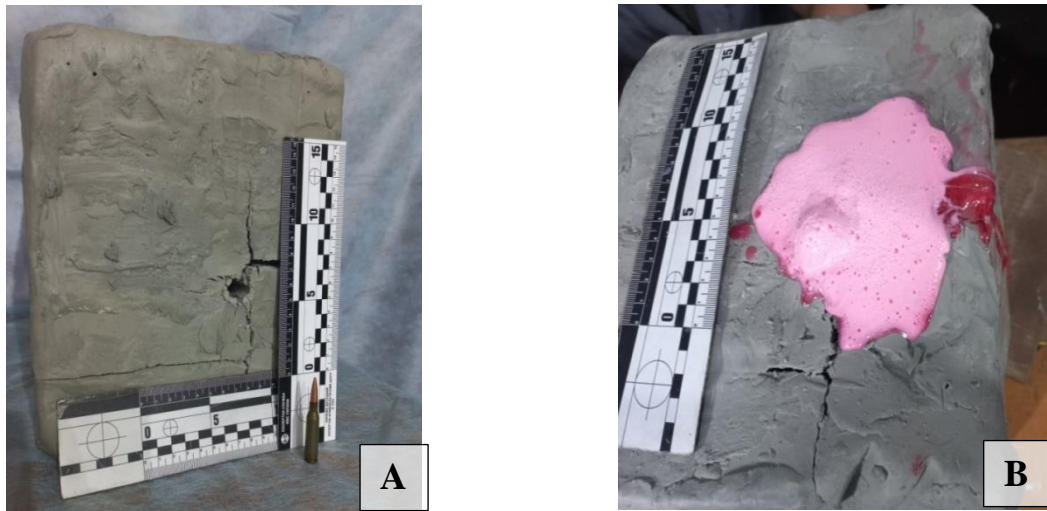ling with liquid plastic using the software "ImageJ", National Institutes of Health by an employee of the Federal Government (Bethesda, Maryland, USA). Area 1 – maximal area of residual gunshot cavity in sagittal projection (cm^2); Perim. 1 – maximal perimeter of residual gunshot cavity in sagittal projection; Circ. 1 – circularity (4π*area/perimeter^2); Round. 1 – roundness, a coefficient showed how close actual form is toward the ideal circle.

The formed shapes 35 minutes after structuring were cleared of ballistic plasticine and their planimetric assessment in sagittal projection was performed using the ImageJ software. The following parameters of the residual wound cavity were determined (see Fig. 8):

✓ maximal perimeter of sagittal projection of residual gunshot cavity;

✓ maximal area of sagittal projection of residual gunshot cavity;

✓ the coefficient of the explosive effect of the projectile (perimeter / area ratio) – the ratio of the perimeter of the maximum sagittal section to its area;

✓ roundness – a coefficient showed how close actual form is toward the ideal circle, 4*area/(π*major_axis^2), or the inverse of the aspect ratio.

Taking into account the importance of evaluating the obtained forms for extrapolating the obtained data into clinical practice with the possibility of visualizing bullets and their fragments, an X-ray examination of the plastic forms of the residual wound cavity was performed in two projections using the OPERA T30 cs apparatus, Italy (Fig. 9).

Figure 9. X-ray examination on the device OPERA T30 cs (Italy) of the received plastic form

The volume of the residual wound cavity was calculated by immersing the obtained plastic impression in a vessel with water – by the volume of the displaced liquid in cubic centimeters. Statistical processing of the obtained data was carried out using the parametric statistics of Student's t-test, the difference between the groups was considered significant if the probability of statistical error was less than 5% ($P < 0.05$). Descriptive statistics are presented in the form of the group arithmetic mean (M) and its mean error (m). Statistical analysis of the material was carried out using the statistical package Microsoft Excel 2010, Version 14.0.7268.5000 (Product Number 02260-018-0000106-48453).

Results and discussion

According to the results of the experimental study, we found that each bullet has its own shape and size of the inlet and outlet openings on the ballistic plasticine. So only for a military cartridge with a caliber of 5.45 mm with bullets "PS" with a steel core "7N6" (group

1), in all 10 observations, both inlet and outlet bullet holes were found (Fig. 10). Considering that in other groups of the experimental study (groups 2, 3 and 4) in no case there was an exit bullet hole (blind gunshot wound), we did not conduct a detailed planimetric assessment of the exit bullet hole, focusing only on the comparative characteristics of the planimetric parameters of the entrance bullet holes. holes depending on the caliber of the bullet and the presence / absence of expansive properties in it.

Figure 10. Inlet (A) and outlet (B) holes from the bullet "PS" 5.45 mm with a steel core "7H6" (photo of the ballistic block of the 1st group)

Since, when the bullets of 5.45 mm "PS" pass through the ballistic plasticine, it passes through it – obviously, some part of the initial kinetic energy that the bullet possesses during the shot remains with it during the flight from the block. Thus, the total energy transferred from the bullet to the ballistic unit will be the smallest when using standard non-expansive 5.45 mm PS bullets, in contrast to all other ammunition analyzed in the presented study. For all other ammunition – 5.45x39 mm cartridges with hollow point "V-Max" bullets (group 2); cartridges 7.62x39 mm (group 3); cartridges 7.62x39 mm with hollow point bullets of the "SP" type (group 4) – only inlet bullet holes of various configurations, presented in Table 1, were found. Such features indicated the presence of a blind nature of damage as a result of plastic deformation of ballistic plasticine. According to the literature, with such injuries, all kinetic energy is transferred from the bullet to the inside of the shot object, leading to significant irreversible damage to the surrounding tissues [1, 2, 10-15]. This fact has great

clinical importance, since upon admission of a wounded person with signs of such damage, the surgeon must be aware of the nature of the damage to organs and tissues in a blind wound will be much greater than due to the formation of zones of secondary necrosis and molecular concussion (commotion) of tissues. In turn, the speed and quality of treatment of the wounded, the volume and tactics of surgical intervention depend on this. Large bullet entry holes were observed with 5.45mm "V-max" (group 2) and 7.62 mm "SP" (group 4) hollow point cartridges – see Fig. 11, 12. Significantly smaller inner holes were presented when using non-hollow point bullets of appropriate calibers (Fig. 10A, 13).

Table 1

Planimetric characteristics of the entrance bullet hole depending on the type of wounding projectile (see also Fig. 5)

Type of bullet	Area of inlet opening		Perimeter of inlet opening		Outer perimeter / area ratio	Inner perimeter / area ratio
	Outer margin $(M\pm m, cm^2)$	Inner margin $(M\pm m, cm^2)$	Outer margin $(M\pm m, cm)$	Inner margin $(M\pm m, cm)$		
1st group: 5,45 mm «PS»	3.341±0.29	1.083±0.15	8.471±0.91	3.757±0.48	2.54	3.47
2 group: 5,45 mm V-max	82.126±7.40	33.794±2.94	40.98±5.72	24.54±2.21	0.50	0.73
3rd group: 7,62 mm «PS»	5.359±0.63	1.426±0.26	12.968±1.21	6.208±0.75	2.42	4.35
4th group: 7.62 mm «SP»	79.705±0.85	29.946±3.89	51.709±5.69	30.422±3.16	0.65	1.02
T_{1-2}	10.64	11.11	5.61	9.19	T – Student's t-test P – error's significance level Lower indexes 1,2,3,4 correspond to appropriate groups	
P_{1-2}	<0.001	<0.000	0.000	0.000		
T_{1-3}	2.91	1.14	2.97	2.73		
P_{1-3}	0.009	0.268	0.008	0.014		
T_{3-4}	70.27	7.32	6.67	7.45		
P_{3-4}	<0.001	<0.001	<0.001	<0.001		
T_{2-4}	0.33	0.79	1.33	1.53		
P_{2-4}	0.749	0.440	0.200	0.145		
green color – significant difference (P < 0.05)			pink background color – difference is NOT significant			

According to the data from table 1, regardless of the caliber of the bullet, the presence of its expansive properties leads to a significant increase in both the perimeter and the area of the inlet bullet hole. Thus, for 5.45 mm bullets, the outer and inner areas were 24.58 and 31.2 times larger, respectively, for "V-max" bullets with expansive properties compared to their non-expansive counterpart (P < 0.001). A corresponding trend was observed in the

planimetric analysis of the bullet inlet hole from the 7.62 mm bullets: the outer and inner areas were 14.87 and 21.0 times larger, respectively, for "SP" bullets with expansive properties (P < 0.001).

Figure 11. Entrance bullet hole 7.62x39 mm, type "SP"

Figure 12. Entrance bullet hole 5.45x39 mm of hollow point bullet «V-Max»

Figure 13. Entrance bullet hole 7.62x39 mm

A similar relationship was observed between the bullet's expansive properties and the increase in the perimeter of the bullet hole, although in quantitative terms, this relationship was not as significant as for the same indicator of the bullet hole area. Thus, for 5.45 mm bullets, the outer and inner perimeters were 4.84 and 6.53 times larger, respectively, for "V-max" bullets with expansive properties (P < 0.001). Outer and inner perimeter for 7.62 mm bullets were 3.99 and 4.9 times higher, respectively, for "SP" bullets with expansive properties compared to non-hollow point analog of the specified caliber (P < 0.001).

The perimeter/area ratio was significantly higher when non-hollow point bullets of different diameters were used (from 2.54 to 4.35), while for bullets with expansive properties this indicator was only 0.5 to 1.02. This is due to the fact that hollow point bullets create an entrance bullet hole of a much larger diameter in comparison with non-expansive analogs, while the value of radial tears formed due to plastic deformation and tissue ruptures is leveled (Fig. 21, 24). This feature must be taken into account when carrying out the primary surgical treatment of a gunshot wound: the border of excision of necrotic tissue in the area of the bullet entrance hole from non-hollow point bullets should be circular, while when the enemy uses hollow point cartridges, the border of excision of necrotic tissue has an irregular shape with a significant deviation from all edges of wound canal. No significant correlation was found between the area and perimeter of the bullet entrance hole and the caliber of bullets with expansive properties (P > 0.15). While for non-hollow point bullets, such a pattern was

found: the outer and inner perimeter of the inlet ball hole was significantly larger (1.53 and 1.65 times, respectively) for 7.62 mm bullets compared to 5.45 mm bullets (P < 0.014).

The total volume and planimetric parameters of the sagittal projection of the residual wound cavity, depending on the type of wound projectile, are summarized in Table 2.

Table 2

The total volume and planimetric parameters of the sagittal projection of the residual wound cavity, depending on the type of wound projectile (see also Fig. 7)

Type of bullet	Total volume of rest wound cavity		Sagittal projection of the rest wound cavity			
	M, cm^3	m, cm^3	Area (M±m cm^2)	Perimeter (M±m cm)	Roundness	Perimeter / area ratio
1st group: 5.45 mm «PS»	253.31	15.8	67.517±8.52	34.985±3.75	0.845	0.52
2 group: 5.45 mm V-max	378.67	32.5	84.574±8.04	41.908±4.21	0.876	0.50
3rd group: 7.62 mm «PS»	852.18	60.3	137.054±18.54	55.786±5.31	0.769	0.41
4th group: 7.62 mm «SP»	517.29	44.9	117.985±13.81	44.711±4.38	0.638	0.38
T$_{1-2}$	3.47		1.46	1.23	T – Student's t-test P – error's significance level Lower indexes 1,2,3,4 correspond to appropriate groups	
P$_{1-2}$	0.003		0.162	0.235		
T$_{1-3}$	9.61		3.41	3.20		
P$_{1-3}$	<0.001		0.003	0.005		
T$_{3-4}$	4.45		0.82	1.61		
P$_{3-4}$	<0.001		0.420	0.125		
T$_{2-4}$	2.50		2.09	0.46		
P$_{2-4}$	0.022		0.051	0.650		
green color – significant difference (P < 0.05)			pink background color – difference is NOT significant			

The table 2 data shown that in all 4 groups of ballistic blocks there were significant differences in the total volume of the residual wound cavity (P < 0.022). An increase in the caliber of the projectile led to an increase in the volume of the residual wound cavity, regardless of the presence or absence of the expansive properties of the bullet. So, with an increase in the caliber of a bullet from 5.45 mm to 7.62 mm for non-hollow point ammunition, the volume of obtained plastic forms increased by 3.36 times (P < 0.001), while for hollow point ammunition the corresponding indicator increased by 1.37 times. (P < 0.022). With the same bullet caliber, a double tendency was observed in the change in the volume of the residual wound cavity. So, when using 5.45 mm bullets, the presence of the expansive properties of the bullets led to an increase in the volume of the plastic mold by 1.49

times (P = 0.003). While modeling the wound canal, where 7.62 mm bullets were used, the opposite pattern was found: bullets with expansive properties significantly reduced the volume of the residual wound cavity by a factor of 1.65 (P < 0.001).

For bullets with a caliber of 5.45 mm "V-max" (group 2) with expansive properties, the enlargement of the wound canal is due to fragmentation of the wounding projectile on the cause of significant collateral plastic deformation of the near-woundary tissues, which leads to significant radial ruptures, which are clearly detected (Fig. 21).

An important regularity was found when comparing the volume of the residual cavity when firing 7.62 mm bullets: despite the additional expansive properties of "SP" bullets (group 4), this does not lead to an increase, but, on the contrary, causes a significant decrease in the wound cavity. This is due to the fact that in the presence of the expansive properties of 7.62 mm bullets, a smaller part of the kinetic energy of the bullets is transformed into irreversible destruction of biological tissues due to plastic deformation, which is manifested by a decrease in the volume of the wound canal in the ballistic plasticine block. Since both groups of 7.62 mm bullets (groups 3 and 4) had only blind wound channels, it is obvious that the total amount of kinetic energy transferred from the bullets to the biological simulator was equal. Therefore, it becomes obvious that when using hollow point bullets of the indicated caliber, a larger part of the kinetic energy of the bullets goes to overcome the elastic deformation of soft biological tissues and does not lead to their instant irreversible destruction, but entails the formation of a zone of secondary necrosis and molecular concussion of tissues, which are the result of the existence of a temporary pulsating cavity, which is formed for a split second at the moment the projectile hits the tissue. This circumstance has great clinical importance, since when performing surgical treatment of wounds after the action of 7.42 mm hollow point bullets, the surgeon must understand that the actual extent of tissue and organ damage is much greater than the area of the wound canal, which he can visualize during the primary surgical intervention. Surgical tactics in such wounded should be aimed at waiting for the formation of significant zones of secondary near-woundary necrosis and significant disturbances in the reparative properties of the wound due to the molecular composition of visually healthy tissues.

Examples of the obtained plastic forms of the wound canal and residual wound cavity for bullets of various diameters and expansive potential are shown in Fig. 14-17.

Figure 14. Plastic form at a shot by a bullet of 5.45x39 mm "PS" with a steel core "7H6"
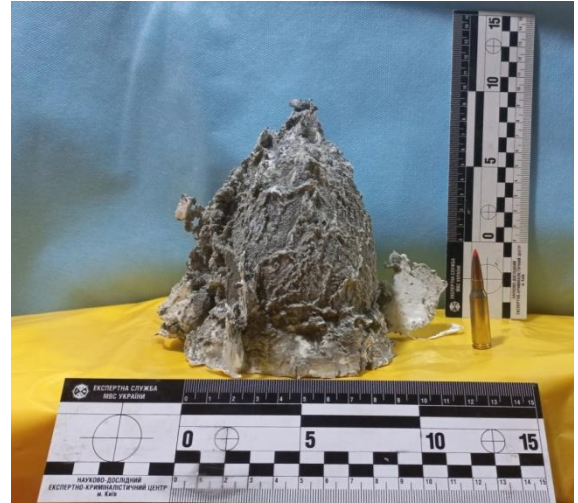

Figure 15. Plastic form when fired with a bullet caliber 5.45x39 mm with expansive properties of the type "V-Max"

Figure 16. Plastic form when firing a bullet caliber 7.62x39 mm

Figure 17. Plastic form at a shot of a bullet of caliber of 7.62x39 mm "SP" type (with expansive properties)

The general view of the received plastic forms after fire shots by various ammunition is presented in Fig. 18.

Figure 18. General view of the obtained plastic forms of wound canals and residual wound cavity when using bullets of different calibers, painted depending on the presence or absence of expansive properties of the wound projectile.

Analysis of the planimetric parameters of the sagittal projection of the residual wound cavity showed that the perimeter and the indicated projection area of the plastic form did not depend on the expansive properties of the bullet. Only for ammunition without expansive properties (groups 1, 3) was a significant increase in the area of 2.03 times ($P = 0.003$) and the perimeter of 1.59 times ($P = 0.005$) of the sagittal projection of the residual wound cavity with an increase in caliber 5.45 mm to 7.62 mm, which correlates with the previously stated considerations about the patterns of change in the total volume of plastic forms.

Thus, our experimental study on modeling modern types of wound canal on ballistic plasticine, as a simulator of biological tissues, allowed us to model the main components arising from a gunshot wound in biological tissues: entrance and exit openings, wound canal, residual wound cavity. The resulting plastic shapes when fired with different bullets differ not only in their size, but also in the spatial configuration that characterizes the wound ballistic properties of different bullets, which must be taken into account in clinical work when providing assistance, performing primary surgical treatment and certain volumes of surgical intervention. After all, each of the obtained forms allows us to understand the specific features of the length, width, volume and spatial configuration of the affected tissues. In addition, the obtained plastic forms are stable and can be additionally examined by other techniques (including radiography, computed tomography, ultrasonography), which is important for further scientific research in modeling and reconstruction of injuries.

According to the results of X-ray examination of plastic molds, we obtained the following results: for the form from the shot of a cartridge 5.45x39 mm with bullets "PS" with a steel core "7N6", considering the through nature of damage to ballistic plasticine, the

boundaries of the entrance and exit holes clearly visualized the cavity has a spindle shape. Due to the deposition of the lead elements of the bullet shell on the walls of the residual wound cavity and the outlet, multiple small single metal fragments are observed (Fig. 19). The form from the shot of cartridges 5.45x39 mm with expansive bullets of the "V-Max" type was characterized by a blind nature of damage with the presence of a deformed and fragmented metal bullet in the blind wound canal, as well as numerous small metal debris ranging in size from 0.1 to 0.3 mm. These fragments were located starting from the entrance bullet hole with maximum accumulation in the residual wound cavity, which has a conical wide shape with indistinct edges with the presence of additional radial ruptures, which are also indicated by other scientists [7, 9], as an equivalent to Fig. 20, 21).
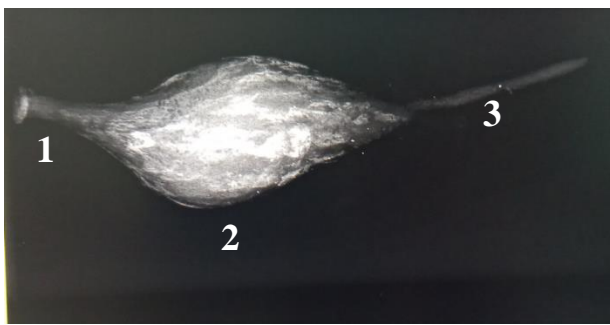

Figure 19. Radiograph of a plastic bullet shot 5.45x39mm "PS", sagittal projection: 1 - entrance bullet hole, 2 - residual wound cavity, 3 - exit bullet hole
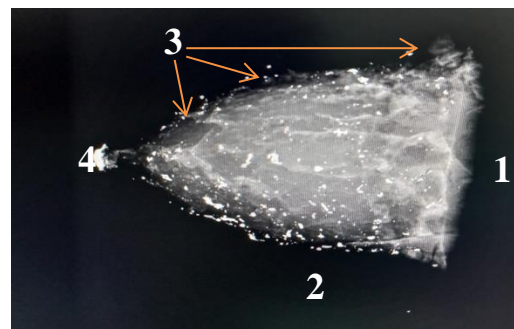

Figure 20. Radiograph of a plastic bullet shot 5.45x39 type "V-Max", sagittal projection:

1 - inlet, 2 - residual wound cavity, 3 - metal fragments, 4 - fragmented bullet
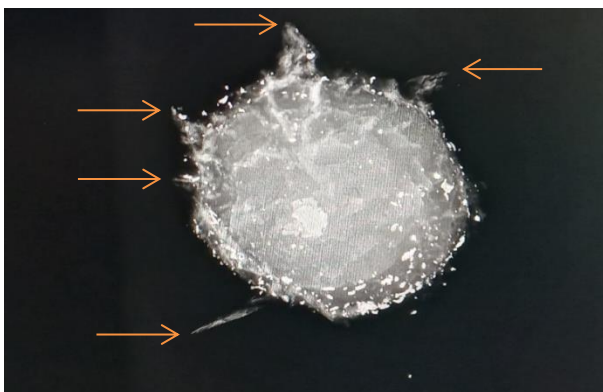

Figure 21. Radiograph of a plastic bullet shot 5.45x39 type "V-Max" frontal projection, perivulnar radial gaps shown by arrows
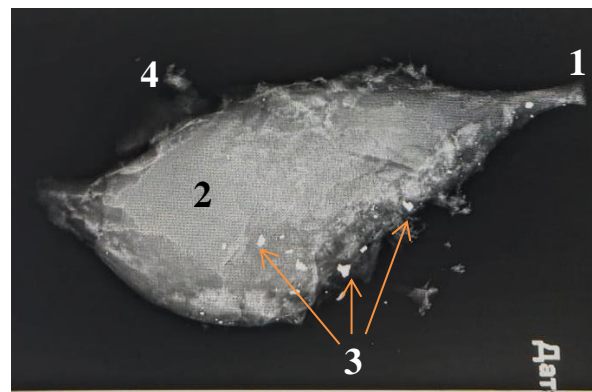

Figure 22. Radiograph of a plastic bullet shot 7.62x39 mm, sagittal projection: 1 - entrance bullet hole 2 - residual wound cavity, 3 - metal fragments, 4 - radial gap
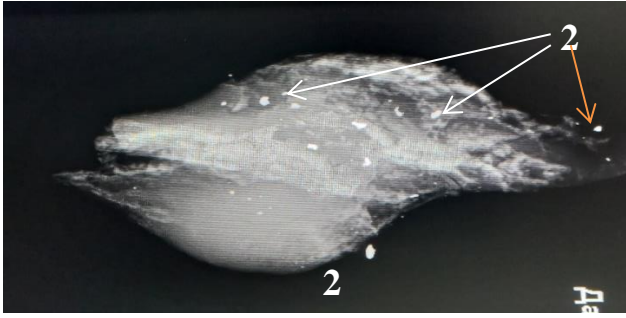
Figure 23. Radiograph of a plastic form of a shot of a bullet of 7.62x39 mm, sagittal projection: 1 - residual wound cavity, 2 - fragments from a bullet
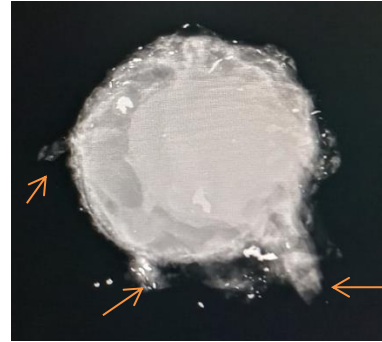
Figure 24. Radiograph of a plastic bullet shot 7.62x39 mm "SP", frontal projection, perivulnar radial gaps shown by arrows
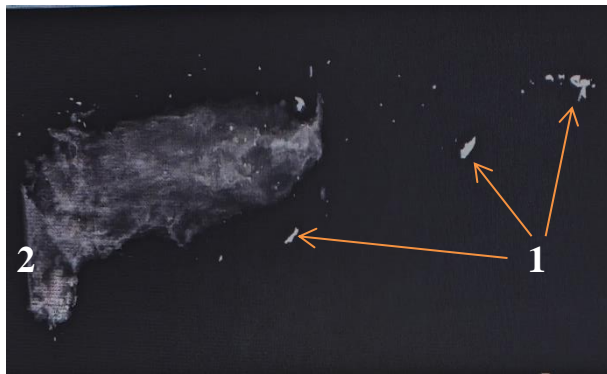

Figure 25. Radiograph of a plastic shot of a bullet 7.62x39 mm "SP", sagittal projection: 1 - metal fragments, 2 - entrance bullet hole

For the form from the shot of cartridges 7.62x39 mm (group 3), a blind nature of damage was characteristic, with the fragmentation of the bullet into multiple fragments ranging in size from 0.5 to 0.8 mm, with their predominant location within the residual wound cavity having an irregular large spindle-shaped with areas of radial ruptures, the entrance hole of the wound canal and the beginning of the formation of the exit spherical canal, which ends blindly, are traced (Fig. 22, 23).

For the form from a shot of cartridges of 7.62x39 mm caliber with bullets of the "SP" type (group 4) was also characterized by a blind nature of damage with the presence of a fragmented and deformed bullet, which was at the blind end of its trajectory in the ballistic block. Fragmented fragments of the ball were located in the residual wound cavity at different distances, were of multiple sizes from 0.2x0.3 mm to 0.5x0.9 mm, perivulnar radial ruptures of the ballistic plasticine were visualized (Fig. 24, 25).

The features of plastic deformation of a biological soft tissue simulator depending on the caliber and expansive properties of the wound projectile are not only valuable in relation to the theoretical features of terminal ballistics but can also be extrapolated and implemented

in clinical practice of military medics. Upon admission of the wounded to the 2nd level of medical support (Role 2, level of the military-mobile hospital), according to the results of X-ray examination, the surgeon can predict the nature and extent of damage by various types of small arms. Understanding the features of terminal ballistics of modern wounded shells, a military surgeon can predict the trajectory of the bullet, anatomical organs and tissues that may be damaged, as well as pre-assess the nature of these damage, determine the exact location of the bullet and its fragments and their subsequent removal. In our opinion, special attention should be paid to the radial ruptures detected by us, which can be overlooked during primary surgery and lead to significant complications in the post-traumatic period: failure of intestinal anastomosis, secondary erosive bleeding, perforation of the hollow organs, post-gun-shot peritonitis.

Thus, based on the results of experimental studies using ballistic plasticine, it was possible to obtain a model of a modern wound firearm caused by a component of plastic deformation of wound tissues, depending on the caliber of small arms and the expansive properties of modern bullets. X-ray examination of the obtained plastic forms of the bullet trajectory clearly demonstrated the difference in the nature of injury by bullets of different caliber, the presence of the phenomenon of fragmentation and deformation of the bullet, the nature of the distribution of bullet fragments in the residual wound cavity, as well as the peculiarities of its spatial configuration. The data obtained have not only theoretical, but also practically applied significance in the clinical work of military surgeons.

Conclusions:

1. When using non-hollow point bullets, the outer area of the bullet entrance hole correlates with the projectile caliber (1.6 times more when using 7.62 mm bullets). For hollow point bullets, the projectile caliber does not significantly affect the area of the bullet entrance hole ($P < 0.05$).

2. Expansive properties of a bullet significantly increase the area of the incoming bullet hole by 14.87 – 31.2 times in comparison with non-hollow point ammunition; similar dependencies were established for the perimeter of the bullet entrance hole.

3. An increase in the caliber of a non-hollow point bullet leads to a significant increase in the area of the sagittal section of the residual wound cavity by 1.59-2.03 times; while the expansive properties of the bullet do not reliably affect either the perimeter or the sagittal section area of the residual wound cavity.

4.   For non-hollow point bullets, the volume of the residual wound cavity correlates to a greater extent with the caliber of the bullet (increases by 3.36 times); whereas for an hollow point bullet, its caliber affects the volume of the residual cavity to a lesser extent (it increases by 1.37 times).

5.   The expansive properties of the bullet have a double effect on the volume of the residual wound cavity: for 5.45 mm bullets, the residual wound cavity increases 1.49 times, for 7.62 mm bullets it decreases 1.65 times.

6.   The use of hollow point bullets 7.62 mm leads to greater collateral damage (zone of secondary necrosis, molecular concussion) due to the dissipation of the kinetic energy of the bullet to the elastic deformation of the near-woundary tissues in comparison with non-hollow point analogs.

7.   The use of 5.45 mm hollow point bullets leads to the formation of a larger volume of irreversible damage due to plastic deformation in comparison with non-hollow point analogs.

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