ORIGINAL ARTICLE

CONTENTS

Introduction of the modern 3d modeling method into the theory and practice of forensic medicine ballistics, caused by gunshot wounds inflicted by firearms with 9mm caliber ammunition

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ABSTRACT
Aim: To explore the capabilities of the modern 3D modeling method for various elements of gunshot wounds caused by 9 mm caliber bullets, intending to integrate these findings into the theory and practice of forensic medicine.

Materials and Methods: The research began with a series of experimental shots, during which the morphological features were examined through their 3D spatial reconstruction. The entire series of experimental shots was conducted using an automatic pistol IZH 70-01 equipped with 9.0 mm caliber bullets. The ballistic clay Roma Plastilina No.1, manufactured in the USA, was utilized as a material for conducting standard ballistic tests according to the standards of the NIJ (National Institute of Justice) and HOSDB (Home Office Scientific Development Branch).

Results: The research was continued during the performance of forensic examinations involving actual cases of gunshot injuries. The dimensions of individual elements of the wound channel were measured in both experimental and expert cases using conventional measuring tools, as well as after their 3D modeling, utilizing graphic editors such as "Agisoft Photoscan" and "3ds max".

Conclusions: In the course of creating and studying experimental and expert 3D models, the dimensions of individual morphological elements of the wound channel were recorded with an accuracy that exceeded the results obtained through measurements using traditional measurement methods by ten times.

KEY WORDS: three-dimensional modeling, gunshot injuries, forensic-medical expertise

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INTRODUCTION

More and more frequently, cases involving the use of firearms become the subjects of forensic investigations worldwide, occurring in civilian life as well as armed conflicts that constantly erupt in various parts of the globe. Additionally, firearms undergo constant modernization and improvement, often involving classified developments in the armaments sector of various countries. This, in turn, necessitates the development of new methods for diagnosing gunshot injuries caused by various types of firearms.

On the one hand, in the theory of forensic medicine, standardized approaches to examining such injuries have already been developed. Therefore, as of today, the results of forensic examination must provide answers to a series of fundamental questions: whether the injury is gunshot-related, the type of firearm used, and the distance from which it was fired, the locations of the entrance and exit gunshot wounds, the direction of the wound channel, the relative positions of the shooter and the victim, and so on. In a whole range of cases, the knowledge accumulated in forensic medicine over the entire period of studying gunshot injuries is sufficient to prepare positive responses to these questions for investigative and judicial authorities.

However, on the other hand, the performance of such forensic examinations encounters objective difficulties due to the use of new, unfamiliar types of firearms. In this context, traditional methodologies may not always ensure a comprehensive and objective determination of the individual identifying morphological features of the fired projectile.

Therefore, the logical and sequential solution for forensic medicine scientists was the pursuit of modern, high-precision research methods that would effectively address these new challenges.

One of the most promising directions in this field is considered to be the implementation of 3D modeling of bodily injuries caused by blunt, sharp, and firearms factors. Photogrammetry of such injuries has yielded significantly more precise and well-founded results [1].

Fig. 1. Gunshot injury of the skin, caliber 9,0 mm.

Other researchers have assessed the effectiveness of studying gunshot injuries using traditional methods such as radiological and ultrasonic techniques. They unequivocally favored more advanced computer tomography, which enables the reproduction of the wound channel in its 3D spatial dimension [2].

Researchers have also demonstrated the high effectiveness of studying gunshot injuries to the skin, internal organs, and bones through their 3D modeling in living individuals and corpses during post-mortem examinations [3].

Some researchers point to the efficiency of the 3D modeling method in the identification of bullets by examining their traces at the micro level [4].

Additionally, the application of this method in computer modeling of damage to protective helmets and their comparison with gunshot injuries in the head region is noteworthy for reproducing the real circumstances of acquiring combat gunshot trauma [5].

AIM

Taking this into account, the primary aim of the research was to explore the capabilities of the modern 3D modeling method for various elements of gunshot injuries, illustrated through experimental and expert cases caused by 9mm caliber ammunition.

Fig. 2. Gunshot injury of the subcutaneous tissue, caliber 9,0 mm.

MATERIALS AND METHODS

These researches were carried out in agreement with the basic bioethical principles of the Council of Europe Convention on Human Rights and Biomedicine (dated 04.04.1997), the Helsinki Declaration of the World Medical Association on the Ethical Principles of Scientific Medical Research with Human Participation (1964-2013), the Order of the Ministry of Health of Ukraine №6 "Instruction on forensic-medical examination" (dated January 17, 1995), the Order of the Ministry of Health of Ukraine №690 (dated September 23, 2009), and taking into account the methodological recommendations of the Ministry of Health of Ukraine "Procedure of exemption of biological objects from dead persons whose bodies are subject to forensic medical examination and pathological examination for scientific purposes" (2018). The Committee on Biomedical Ethics of the Bukovinian State Medical University did not reveal any violations of moral and legal norms during these scientific researches (Protocol No1 dated 21.09.2023).

The series of experiments were conducted at the Chernivtsi Scientific Research Expert-Criminalistic Center, equipped with the projectile flight speed recorder VBX-2020. An example of a firearm used in the experiments was the IZH 70-01 automatic pistol loaded with 9.0 mm caliber ammunition. Targets were covered with pigskin, including the subcutaneous adipose layer, and were placed at a distance of 1.5 meters from the muzzle of the firearm. As a target, ballistic clay Roma Plastilina No.1, produced in the USA for conducting stand ballistic tests according to the standards of the National Institute

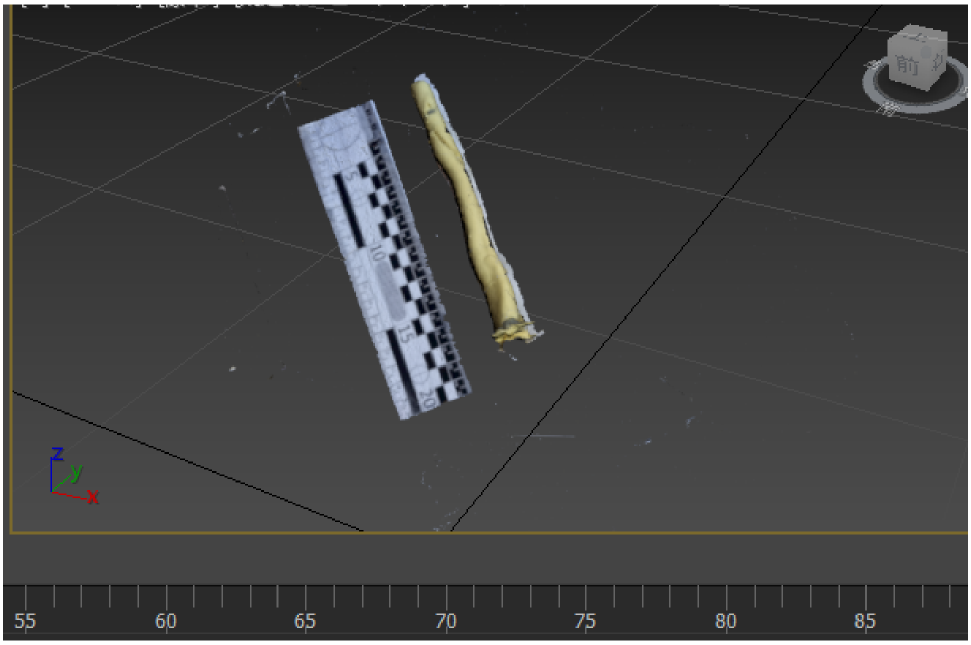

Fig. 3. 3D model of the gunshot wound canal caused by bullet, caliber 9,0 mm.

of Justice (NIJ) and Home Office Scientific Development Branch (HOSDB), was used. This ballistic clay, due to its physical and technical characteristics, accurately reproduces the soft tissues of the human body (skin, subcutaneous adipose tissue, muscles, parenchymal organs), especially when heated to a temperature of 35-38 °C.

After the shots were fired, digital photographs of the injuries on the skin, subcutaneous adipose tissue, and the plastiline block at the entry and exit points of the bullet were taken. Subsequently, all elements of the gunshot injuries were measured using traditional methods for investigating linear dimensions of objects – rulers and calipers. Circular photogrammetry of the entrance wound and subcutaneous adipose tissue was then carried out at different angles: 30°, 45°, 60°, and 90°. For this purpose, the skin fragment with the injury was placed on a turntable with a white background and additional lighting provided by spherical LED lamps (Fig. 1 and Fig. 2).

The next step involved uploading all the JPEG format photos into the computer program "Agisoft Photoscan". In this program, 3D models were constructed, and then textures were created, resulting in a textured 3D model of the entrance wound in the skin and subcutaneous adipose tissue. These textured models were exported in "OBJ" format to the "3ds max" program, where scaling and measurements of the wound dimensions were performed.

In the process of progressively investigating the wound channel, the next step was to create its volumetric cast in a ballistic clay block. For this purpose, we utilized alginate material Tropicalgin (by "Zhermack", Italy), prepared according to the manufacturer's recommended instructions. This material is characterized by high precision in capturing object impressions and allows for the reproduction of the finest details of the wound channel. After pouring, solidifying, and cleaning the material from clay, a clear sample of the wound channel was obtained. It represented an accurate replica made from the alginate material, which underwent photography, photogrammetry, and the creation of a 3D model using the same methodologies as with the skin and subcutaneous adipose tissue (Fig. 3).

The obtained digital data were initially recorded in electronic spreadsheets to standardize their input, grouping, storage, and computation. Calculations and statistical analysis were performed using the Statistica 13.5.0.17 software by TIBCO Software Inc. (ZZS9990000099100363DEMO-L).

The assessment of the distribution type of the data was conducted by determining the measure of central tendency between the mean, mode, and median, as well as skewness (symmetry) and kurtosis (excess). In the computation of statistical values, the following were calculated: the sample mean (M), standard deviation (SD), standard error of the mean (m), as well as the minimum (min) and maximum (max) values of the variables.

For assessing the strength of relationships, Pearson's correlation analysis was employed. In this context, the evaluation of the strength of correlational ties utilized a six-level gradation: up to 0.16 – unsatisfactory, 0.17-0.33 – satisfactory, 0.34-0.50 – below average, 0.51-0.67 – average, 0.68-0.84 – above average, and greater than 0.85 – high. Results were considered statistically significant at $p<0.05$.

Table 1. Parameters and morphological signs of experimental gunshot injuries caused by the automatic pistol IZH 70-01, caliber 9,0 mm (N=15)

Parameter	Average value and mean arithmetic error (M±m)	Minimum value (min)	Maximum value (max)	Standard deviation (S.D.)
1.Physical parameters of the bullet				
Initial velocity, m/sec	310±0,9411	304	315	3,6450
Kinetic energy of the bullet, (Joule)	302,732±6,4905	284,641	390,287	25,1378
Specific energy of the bullet, (Joule/mm^2)	4,461±0,0277	4,284	4,599	0,1072
2.Morphological signs of the gunshot entry wound				
Diameter of the entry wound, cm	0,887±0,0091	0,8	0,9	0,0352
Dimensions of the defect tissue, cm	0,367±0,0187	0,3	0,5	0,0724
Dimensions of the abrasion ring, cm	0,320±0,0175	0,2	0,4	0,0676
Dimensions of the deposition ring, cm	0,380±0,0175	0,3	0,5	0,0676
3. Morphological signs of the gunshot wound canal				
Diameter of the wound canal in the initial part, cm	0,7±0,0507	0,5	0,9	0,1964
Diameter of the wound canal in the initial part (3D modelling), cm	0,9158±0,0090	0,841	0,949	0,0349
Diameter of the wound canal in the middle part, cm	1,63±0,0621	1,2	2,1	0,2404
Diameter of the wound canal in the middle part (3D modelling), cm	1,655±0,0643	1,215	2,142	0,2490
Diameter of the wound canal in the exit part, cm	2,19±0,0636	1,8	2,6	0,2463
Diameter of the wound canal in the exit part (3D modelling), cm	2,227±0,0627	1,836	2,638	0,2430

ETHICAL APPROVAL

The research protocol and informed consent form were approved by the Commission on Biomedical ethics in biomedical scientific research of the Bukovinian State Medical University (Protocol No.1 dated 21.09.2023).

RESULTS

The results of all 15 shots, after statistical processing, were grouped into three data blocks. The first data block provided characteristics of the bullet's physical parameters after the shot and included initial velocity, kinetic energy, and specific energy of the bullet. The second data block pertained to the morphological features of the entrance gunshot wound and was represented by measurements of the entrance wound diameter, measured with traditional measuring tools and established during 3D modeling, as well as the dimensions of tissue defects and deposition rings. The third data block illustrated the morphological features of the wound channel, measured at various intervals using traditional methods and during its 3D modeling. All three data blocks were grouped into a table and subjected to a comparative analysis (Table 1).

The digital data in this table indicate a slight discrepancy between the values of the average initial bullet velocity and its specific energy in shots fired from the IZH 70-01 automatic pistol, as well as their minimum and maximum values. At the same time, a somewhat larger range of values was observed in the minimum, average, and maximum values of its kinetic energy.

As for the morphological features of the wound, 3D technologies have enabled the recording of significantly more precise average dimensions, as well as minimum and maximum values of the entrance wound diameter, tissue defect, and the dimensions of the ring of deposition and abrasion than previously achieved using calipers and rulers.

This also applies to the morphological features of the wound channel. The diameters of its middle portion, at the exit, and especially in the initial part were determined with greater precision through 3D modeling and the use of computer technologies in determining the linear dimensions of the investigated objects.

All described injuries had a perforating nature with a wound channel length of 16.0 cm (across the entire length of the ballistic gel block), and the skin wounds were round in shape with finely serrated edges.

Table 2. Morphological signs of the gunshot injury (forensic medicine case, determined caliber – 9,0 mm)

Part of the wound canal	Dimensions measured by traditional means, centimeters	Dimensions fixed by 3D modelling, centimeters	Additional characteristics
Entry wound	0,87x0,6	0,884x0,603	Presence of the defect tissue, abrasion ring up to 0,5 mm, margins are fine notched
Buttonhole fracture of the right temporal bone (external plate)	0,91x0,6	0,914x0,613	Round form with fine notched edges
Buttonhole fracture of the right temporal bone (internal plate)	1,2x1,0	1,245x1,124	Crater-like form
Injury of the right temporal lobe of brain	1,3x1,1	1,343x1,150	Entry
Injury of the left temporal lobe of brain	1,5x0,9	1,512x0,934	Exit
Buttonhole fracture of the left temporal bone	1,6x0,9	1,628x0,941	Margins are uneven with small fissured cracks
Exit wound	1,9x0,5	1,932x0,542	Fissured form, margins without abrasions, turned outwards

DISCUSSION

The subsequent scientific discussion revolved around establishing and analyzing correlational relationships between shooting parameters and identified morphological features of individual elements of gunshot injuries. Correlational analysis revealed direct average-strength correlations between the diameter of the wound channel at its entrance, determined by 3D modeling methods, and the initial velocity of the bullet and its specific energy (r=+0.55), with p=0.04.

Strong (high) direct correlations were identified between the diameters of the wound channel in its middle part and the initial velocity of the bullet and its specific energy, measured both by traditional methods (r=+0.90 and r=+0.85) and 3D modeling techniques (r=+0.89 and r=+0.85) respectively (p=0.02).

Even stronger direct correlation links were found between the diameters of the wound channel at its exit and the initial velocity of the bullet and its specific energy, measured by both traditional methods (r=+0.94 and r=+0.89) and 3D modeling techniques (r=+0.94 and r=+0.90) respectively (p=0.01).

Average direct correlations were observed between the initial velocity of the bullet and tissue defect (r=+0.54), as well as between the initial velocity of the bullet and the dimensions of the ring of deposition (r=+0.55), at p=0.04.

The described direct correlation relationships discussed may indicate an objective dependence and an increase in the dimensions of the diameters of the initial section of the wound channel during 3D modeling, especially the dimensions of the wound channel in its middle part and at the exit, as the initial velocity and specific energy of the bullet increase. The indicators of the initial velocity also directly influence the enlargement of tissue defects and the ring of deposition around the entrance wound in cases involving the use of a 9.0 mm caliber automatic short-barreled weapon.

Other researchers have also utilized 3D modeling of firearm injuries caused by short-barreled automatic weapons with a 9.0 mm caliber (Luger pistol). They observed similar morphological changes that assisted them in conducting differential diagnoses from firearms of larger calibers [6]. Objective morphological differences identified through 3D modeling of gunshot wounds caused by 9.0 mm firearms, compared to other calibers, have been described by other authors as well [7].

The described methodologies were applied by us during a forensic examination in the case of a fatal injury to the victim from automatic firearms. The body of an unidentified person was brought to the morgue with a through gunshot wound to the head. During the examination, a gunshot wound was found in the right temporal region, a perforated fracture of the right temporal bone, damage to the brain, and a perforated fracture of the left temporal bone.

All elements of the gunshot wound channel were measured using standard metric methods, followed by circular photogrammetry, and their 3D model was created (Table 2). This provided a factual basis for determining the caliber of the unknown firearm – 9.0 mm, along with a series of three-dimensional illustrations that assisted in the successful investigation of this crime later on.

CONCLUSIONS

The implementation of 3D modeling techniques allows for a 10-fold increase in accuracy in capturing the morphological features of the main elements of gunshot wounds. It enables the creation of 3D models of both individual components of gunshot injuries and the entire wound channel, opening up new possibilities for visualization, long-term storage, and expert analysis.

Example of 3D modeling of gunshot wounds caused by automatic firearms with a caliber of 9.0 mm demonstrates new directions in the theory and practice of forensic medicine regarding the possibilities of conducting differential diagnostics between gunshot projectiles of different calibers in the future.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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