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IMPROVEMENT OF FORENSIC MEDICAL DIAGNOSIS OF PROJECTILE TYPE INJURIES FROM AUTOMATIC FIREARM CHAMBERED IN 5.45 mm CALIBER THROUGH SPATIAL 3D MODELING

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Abstract. Improvement of forensic medical diagnosis of projectile type injuries from automatic firearm chambered in 5.45 mm caliber through spatial 3D modeling. Zmiyevska Y.G., Tryubner K., Savka I.G. *Spatial 3D modeling has become one of the modern and most accurate evidential methods of research, carving out its niche in various fields of medical science and practice. Therefore, our focus has been on laying the groundwork for its implementation in the process of conducting forensic medical examinations of gunshot injuries, which have garnered significant attention from all forensic physicians, particularly after unprovoked aggression from Russia and the onset of active hostilities in our country. The aim of the study was to improve the forensic medical diagnosis of projectile type in injuries from automatic firearm AKS-74U chambered in 5.45x39 mm caliber by utilizing spatial 3D modeling of specific elements within the wound channel. The entire series of experimental shots was conducted using an AKS-74U firearm, with a bullet caliber of 5.45x39 mm. As the research material, Roma Plastilina Number 1 ballistic clay, manufactured in the USA, was used for conducting standardized ballistic tests according to NIJ (National Institute of Justice) and HOSDB (Home Office Scientific Development Branch) standards. The series of experiments consisted of 15 gunshots; then the physical characteristics of the bullet, main morphological elements of the wound of skin and different portions of wound channel were investigated (195 measurements in general). The morphological features of individual elements within the wound channel were measured using conventional measurement tools, and also after their 3D modeling using graphic editors such as "Agisoft Photoscan" and "3ds max." Direct and strong correlations (ranging from 0.60 to 0.72) have been established between the initial velocity, kinetic energy, specific energy of bullet, and the diameter of the entry wound in 3D modeling, as well as the diameters of the wound channel in its central portion, measured both by conventional measuring tools and based on the results of their 3D modeling (p=0,02). Furthermore, inverse correlation relationships of moderate strength (ranging from -0.63 to -0.66) have been detected between the initial velocity, kinetic energy, specific energy, and the presence of abrasion collar around the entry wound (p=0,03). The created conditions allow to conduct the differentiation in diagnosing the type of projectile, the identification and study of new characteristics of key elements in firearm-related injuries, and improvement in measurement accuracy. They also enhance clarity and objectivity during the execution of forensic medical examinations in cases of combat-related firearm injuries.*

Реферат. Удосконалення судово-медичної діагностики виду травмуючого снаряда при ушкодженнях з автоматичної вогнепальної зброї калібром 5,45 мм шляхом просторового 3Д-моделювання. Змієвська Ю.Г., Трюбнер К., Савка І.Г. *Просторове 3Д-моделювання є одним із сучасних і найбільш точних доказових методів дослідження, яке вже зайняло свою нішу в багатьох напрямках медичної науки і практики. Тому нами було зосереджено увагу на створенні підґрунтя для його впровадження в процес виконання судово-медичної експертизи вогнепальної травми, яка перебуває в центрі уваги всіх судових медиків, особливо після неспровокованої агресії росії та початку активних бойових дій на території нашої країни. Метою нашої роботи було вдосконалення судово-медичної діагностики виду травмуючого снаряда при ушкодженнях з автоматичної* *вогнепальної зброї калібром 5,45х39 мм шляхом просторового 3Д-моделювання окремих елементів ранового каналу. Уся серія експериментальних пострілів здійснена з АКС-74У, калібр кулі 5,45х39 мм. Як дослідний матеріал використовували балістичний пластилін Roma Plastilina № 1, виробництва США, для проведення стендових балістичних випробувань за стандартами NIJ (National Institute of Justice), HOSDB (Home Office Scientific Development Branch). Серія експериментів складалася з 15 пострілів, у кожному з яких були виміряні фізичні параметри кулі, морфологічні ознаки вхідної вогнепальної рани та ранового каналу на різних його проміжках із загальною кількістю 195 вимірювань. Морфологічні особливості окремих елементів ранового каналу вимірювали класичними засобами вимірювання, а також після проведеного їх 3Д-моделювання, за допомогою графічних редакторів «Agisoft Photoscan» та «3ds max». Установлено прямі середні та сильні за значеннями кореляційні зв'язки (від 0,60 до 0,72) між початковою швидкістю, кінетичною і питомою енергією кулі та діаметром вхідної рани при 3Д-моделюванні, діаметрами ранового каналу в середній його частині, виміряними як традиційними вимірювальними засобами, так і за результатами їх 3Д-моделювання (р=0,02). Також виявлено обернені кореляційні зв'язки середньої сили за їх значеннями (-0,63-0,66) між початковою швидкістю, кінетичною і питомою енергіями та пояском осаднення довкола вхідної рани (р=0,03). Створені передумови дозволяють проводити диференційну діагностику виду травмуючого снаряда, виявляти та вивчати нові ознаки основних елементів вогнепальних ушкоджень, підвищити точність вимірювань, наочність та об'єктивність під час виконання судово-медичних експертиз у випадках бойової вогнепальної травми.*

Without a doubt, the orchestration of forensic medical examinations in instances of injuries resulting from diverse forms of automatic firearms stands as the foremost imperative for the forensic medical service of Ukraine presently. This matter assumed extraordinary gravity following the comprehensive incursion of the russian federation onto the sovereign territory of our state in the year 2022.

The predominant form of automatic firearms employed by military personnel within active combat zones remains the AK-74, featuring a caliber of 5.45 mm.

Within extant scientific literature, there exist discrete scholarly publications addressing the conduct of experimental firearm discharges with the AK-74, caliber 5.45x39 mm, directed against diverse impediments: glass blocks, fragments of wood particle board at varying angles (ranging from 70̊ to 90̊), and at distances of 1, 2, and 3 meters [1].

The technical specifications of the AK-74, with a caliber of 5.45x39 mm, are also documented in publications by foreign researchers who compare it with other examples of automatic firearms utilized by NATO member countries [2].

Researchers additionally emphasize that projectile discharged from contemporary automatic firearms possess considerable kinetic energy and, upon entering the human body, may undergo various rotational movements and fragmentations. These factors, in turn, influence both the formation of temporary cavitation and the development of a permanent wound channel [3].

While numerous researchers have explored various forensic medical criteria for gunshot injuries in recent years, many aspects of these criteria remain incompletely elucidated. Among them are criteria for establishing the nature of a gunshot injury based on its morphological features and firearm characteristics, determining the direction of the rotational movement of a gunshot projectile, investigating skin and subcutaneous adipose tissue injuries resulting from different types of gunshot projectiles, and so forth [4, 5].

To contribute to the resolution of the aforementioned issues, the application of a modern and promising research method such as 3D spatial modeling of various elements of bodily injuries could prove instrumental. In recent years, both domestic and foreign researchers have increasingly incorporated this method into the practice and theory of forensic medicine [6, 7, 8, 9, 10].

The objective of our study was to enhance forensic medical diagnostics regarding the type of injuring projectile in injuries caused by automatic firearm with a caliber of 5.45x39 mm. This was achieved through the utilization of spatial 3D modeling of distinct elements within the wound channel.

MATERIALS AND METHODS OF RESEARCH

In the course of the experimental phase of the study, the AKS-74U was utilized as the automatic firearm, equipped with 5.45x39 mm cartridges. These munitions feature a pointed bullet with an actual diameter of 5.7 mm and a bullet mass of 3.42 g. The core itself, crafted from steel, weighs 1.43 g, while the bullet casing is made of copper.

The targets were positioned at a distance of 1.5 meters from the muzzle of the weapon. Shots were executed using a standardized apparatus designed for testing various types of firearms at the Chernivtsi Scientific Research Expert-Criminalistic Center. The apparatus is equipped with a projectile velocity recorder, the VBH-2020.

For experimental purposes, ballistic gelatin "Roma Plastilina No. 1", manufactured in the United States, was employed to conduct standardized ballistic tests following the protocols of NIJ (National Institute of Justice) and HOSDB (Home Office Scientific Development Branch). This material, owing to its density and plasticity, effectively simulates soft elastic biological tissues, especially when heated to a temperature of 35-38°C, which closely approximates the human body temperature.

Before conducting the experiments, fresh pigskin with a subcutaneous fat layer measuring 1.8-2 cm in thickness was affixed to the front of the block. This material closely resembles human skin in its characteristics.

Following the discharges, a photographic record of the obtained results was made. Damages formed on the skin, subcutaneous adipose tissue, and the ballistic gelatin block at the entry and exit points of the projectile were separately documented. Subsequently, all elements of gunshot injuries were measured using a ruler and calipers. Further analysis involved circular photogrammetry of the entry wound at various angles: 30̊, 45̊, 60̊, and 90̊. To achieve this, the skin fragment with the injury was placed on a rotating table with a white background and additional illumination provided by spherical LED lamps. The same photographic procedure was conducted on the side of the subcutaneous adipose tissue.

Subsequently, the captured images in JPEG format were uploaded into the computer program "Agisoft Photoscan". Initially, camera alignment was performed, and unnecessary background elements were removed through the creation of masks. A dense point cloud was then generated to facilitate the subsequent creation of the actual model of the bodily injury. Upon completing the model, textures were applied, resulting in a textured 3D model of the entry wound on the skin and subcutaneous adipose tissue. Following the acquisition of the textured model, it was exported in "OBJ" format for further utilization in the "3ds max" program, allowing for scaling with measurements of the wound dimensions [6, 11].

Our next step involved creating a replica of the wound channel in the ballistic gelatin block. For this purpose, we utilized alginate material, specifically Tropicalgin from the "Zhermack" company in Italy. The preparation of this alginate compound adhered to the recommended manufacturer instructions. Notably, this impression material boasts rapid setting times due to the chromatic alginate content, and it distinguishes itself with high precision in reproducing impression details. This, in turn, allows for the replication of the finest details of the wound channel.

The specified mixture was prepared in a disposable syringe with a capacity of 100 ml using the following method: the dry alginate material was poured into the syringe without the plunger using a measuring spoon, and distilled water was added at a ratio of 15 ml of water per spoonful of dry substance. Subsequently, the mixture was stirred with a wooden stick for 30-45 seconds (depending on the volume of the mixed material). The plunger was then inserted into the syringe, and under pressure, the alginate mixture was poured into the created wound channel in the ballistic gelatin block (the overall processing time did not exceed 2 minutes and 35 seconds).

Following the mentioned procedures, careful layer-by-layer removal of clay was performed using a plastic spatula until obtaining a clean model of the wound channel. After the model of the wound channel had solidified, any remnants of ballistic clay were meticulously cleared using tweezers. The resulting clean model of the wound channel, presented as an exact replica in alginate material, was photographed in accordance with all requirements for scale photography.

After this, the wound channel model was placed on a rotating table with a monochrome surface, a white background, and the capability of additional illumination using spherical LED lamps. A stepwise circular photogrammetry was then conducted at various angles (30̊, 45̊, 60̊, 90̊). The process of creating a 3D model for this wound channel was carried out similarly to that performed with the skin and subcutaneous adipose tissue.

The entire series comprised 15 experimental shots, each of which involved measuring the physical parameters of the projectile (initial velocity, kinetic and specific energy), morphological features of the entry wound (diameter, tissue defect size as the greatest distance between its edges, and the width of the deposition ring). These measurements were conducted using both traditional methods and 3D technologies. Additionally, the diameters of the wound channel at its midpoint and exit were measured, employing both traditional means and 3D technologies. Consequently, the total number of measurements amounted to 195, and the damages on all ballistic blocks, each 16 cm in length, exhibited a penetrating nature.

The data from the conducted experiments were entered into corresponding maps of experimental studies. Subsequently, kinetic energy (E_k) of the projectile was calculated using the formula:

$$\boldsymbol{E_k = \frac{mv^2}{2}},$$

where: E_k – is the kinetic energy, m – is the mass of the projectile, v – is the velocity of the projectile.

Additionally, specific energy (E_s) of the projectile was calculated using the formula:

$$\boldsymbol{E_{s=}\frac{2mv^2}{\pi d^2}},$$

where: E_s – is the specific energy, m – is the mass of the projectile, v – is the velocity of the projectile, π – is the mathematical constant with a value of approximately 3.14, and d – is the actual diameter of the projectile.

The primary data of the scientific research were entered into an electronic database that we developed to standardize data input, storage, and computation of results. Calculations and statistical analyses were performed using the Statistica 13.5.0.17 TIBCO Software Inc. (ZZS9990000099100363DEMO-L).

To assess the distribution of data, measures of central tendency including mean, mode, and median were determined. Additionally, skewness (symmetry) and kurtosis (excess) were calculated. When computing statistical values, the following were determined: mean (M), standard deviation (SD), standard error of the mean (m), as well as the minimum (min) and maximum (max) values of the variables.

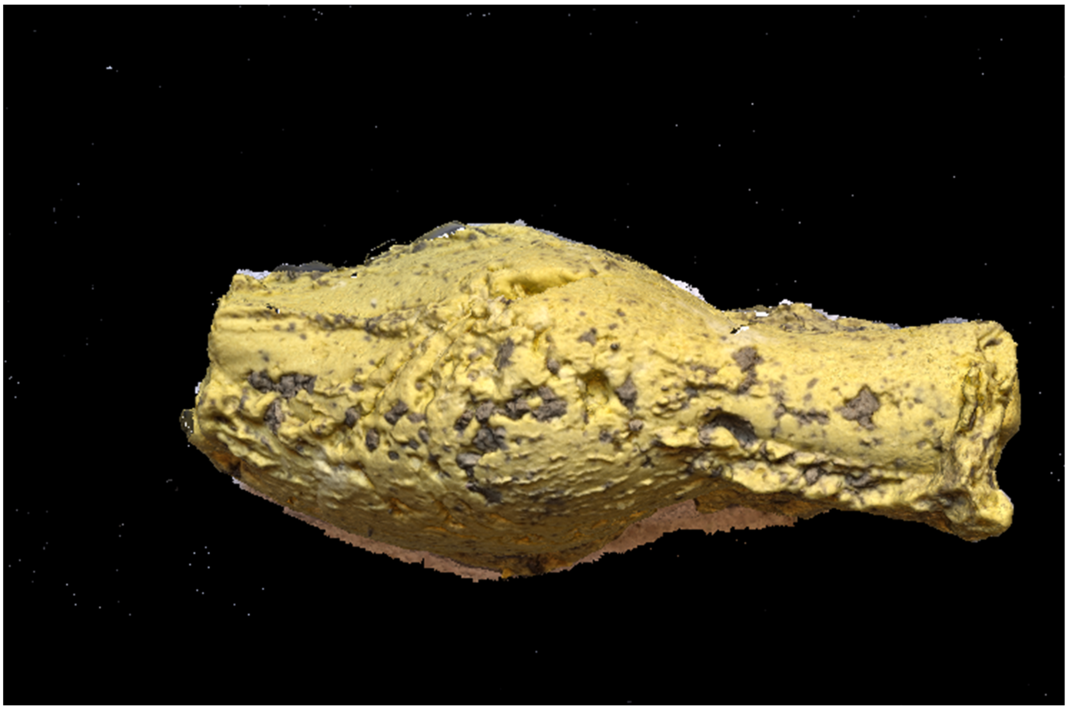
To assess the strength of relationships, Pearson correlation analysis was employed. The evaluation of the strength of correlational connections was categorized into six levels: up to 0.16 – unsatisfactory, 0.17-0.33 – satisfactory, 0.34-0.50 – below average, 0.51-0.67 – average, 0.68-0.84 – above average, and greater than 0.85 – high [12].

Results were considered statistically significant at $p<0.05$.

RESULTS AND DISCUSSION

The results of the experimental research group were conditionally divided into three components: those characterizing the properties of the used firearm (initial velocity, kinetic and specific energy of the projectile), morphological features of the entrance gunshot wound (diameter of the entrance wound measured by traditional means and established during 3D modeling, dimensions of tissue defect, and width of the deposition ring), and the wound channel (measured at various segments using traditional methods and during 3D modeling).

A significant advantage compared to traditional research methods in forensic medicine is that the created textured 3D model of the wound channel can be rotated in different coordinate axes, allowing measurement of dimensions for both specified segments and the entire model (Fig.).



Textured 3D model of the wound channel from a 5.45 caliber bullet shot

Another advantage of processing the model in these software applications is that, compared to conventional metric measurement methods (ruler, caliper), it allows obtaining dimensions with precision up to 0.001 cm.

These approaches enable a comprehensive examination of all elements of gunshot injuries and, if necessary, facilitate their comparison.

The obtained research results, after their statistical processing, were grouped into a table and subjected to comparative analysis (Table).

The digital data from this table indicate a slight discrepancy between the values of the average initial bullet velocity in shots from the AKS-74U, the values of kinetic and specific bullet energy, and their minimum and maximum magnitudes.

The 3D modeling results revealed a significantly more precise diameter of the entrance wound compared to traditional investigative methods such as ruler or caliper measurements. The identification of tissue defects and the presence of a deposition ring (belt) in the middle part of the entrance gunshot wound, although small in size, aligns with classical concepts of the main morphological features of gunshot injuries. In our case, it adds additional diagnostic value through the establishment of new correlational connections.

Parameters and morphological features of experimental gunshot injuries from AKS-74U, caliber 5.45x39 (N=15)

Indicator	Mean value and standard error of the mean (M±m)	Minimum values (min)	Maximum values (max)	Standard deviation (S.D.)
Initial velocity (m/s)	743±0.9207	735	749	3.5657
Kinetic energy of the bullet (Ek) (Joules)	944.024±2.3381	923.785	959.312	9.0552
Specific energy of the bullet (Es) (Joules/mm²)	37.037±0.0793	36.573	37.613	0.3072
Diameter of the entrance wound (cm)	0.507±0.0067	0.5	0.6	0.0258
Diameter of the entrance wound in 3D (cm)	0.543±0.0045	0.521	0.585	0.0175
Defect dimensions (largest distance between wound edges) (cm)	0.113±0.0091	0.1	0.2	0.0352
Dimensions (width) of the deposition ring (cm)	0.127±0.0118	0.1	0.2	0.0458
Diameter of the wound channel in the middle part (cm)	8.420±0.0562	8.1	8.8	0.2178
Diameter of the wound channel in the middle part in 3D (cm)	8.473±0.0498	8.125	8.779	0.1930
Diameter of the wound channel at the exit (cm)	3.313±0.0506	3.0	3.7	0.1959
Diameter of the wound channel at the exit in 3D (cm)	3.341±0.0471	3.047	3.725	0.1824

The diameter of the wound channel in its middle part was more than 2.5 times larger than the diameter of the wound channel at the exit, both measured by traditional methods and through the use of 3D modeling tools, with relatively small discrepancies between their minimum and maximum values.

All described injuries were through-and-through, spanning the entire length of the ballistic clay block (16.0 cm). The entrance wounds were round, with a diameter of 0.5 cm and relatively uneven, finely undulating edges.

Further analysis of correlation relationships between shooting parameters and established morphological features revealed direct moderate (average) to strong (above average) correlations (ranging from 0.60 to 0.72) between the initial velocity, kinetic and specific energy, and the diameter of the entrance wound in 3D modeling, as well as the diameters of the wound channel in its middle part, measured both by traditional means and through 3D modeling (p=0.02). Additionally, inverse correlation relationships of moderate (average) strength (-0.63 to -0.66) were identified between the initial velocity, kinetic and specific energies, and the width of the ring of settling around the entrance wound (p=0.03).

Thus, continuing the discussion of the research results, it can be concluded that the increase in the initial velocity of the bullet and its kinetic and specific energy, respectively, leads to an increase in the diameter of the entrance wound, which can be reliably documented through the use of the 3D modeling method. These same factors also objectively contribute to an increase in the diameter of the wound channel in its middle part.

Moreover, higher values of the initial bullet velocity, kinetic energy, and specific energy contribute to a decrease in the width of the deposition ring around the entrance wound, which is evidently associated with a reduction in the time of their interaction during the bullet's contact with the skin surface.

It is worth noting that even today, in forensic medicine, when identifying the type of injuring projectile, researchers prefer morphological features revealed during the examination of entrance and exit gunshot wounds [13]. This task can be particularly effectively addressed by identifying barrel imprints on the skin's surface, left by the specific firearm used (stamp marks). However, such a morphological feature can only be detected in cases of close-range shots, which occur relatively infrequently [14, 15].

The majority of gunshot wounds are inflicted at both close and long distances. Therefore, researchers suggest investigating various sections of the wound channel and, if possible, comparing them with the physical parameters of the firearm and ammunition used to identify the type of projectile [16]. As an example, one can mention studies where researchers report a detailed examination of the wound channel through its three-dimensional reconstruction, establishing the exact trajectory and type of bullet in cases of firearm injuries to individuals [17].

Therefore, we consider our proposed approach to improve the diagnosis of the type of projectile by utilizing three-dimensional spatial reconstruction tools for various parts of the wound channel promising for conducting further experiments involving firearms of different calibers and in the process of forensic medical examinations.

Additionally, during the conducted series of experimental studies, it was determined that the 3D modeling method allows for a more precise investigation of the linear dimensions of all components of firearm injuries, thereby enhancing forensic medical diagnosis of the type of projectile in automatic firearm shots.

CONCLUSION

1. The utilization of modern 3D modeling techniques in forensic medical practice allows for the creation of 3D models of both individual components of firearm injuries and the entire wound channel. This opens up new possibilities for their long-term storage in an electronic archive, remote examination, and expert assessment by commissions.
2. The enhanced capabilities enable the precise measurement of dimensions for both individual elements of firearm injuries and the entire wound channel, significantly improving accuracy.
3. Thus, new conditions have been established for conducting differential diagnosis of the type of projectile, exploring novel features of firearm injuries, and enhancing the clarity and objectivity of forensic conclusions in such examinations.

Contributors:

Zmiyevska Y.G. – realization of experiments, data selection, 3D modelling and digital morphometry, preparing the draft of article;

Tryubner K. – conceptualization of the research, choice of the research methodology, consultation and evaluation of the morphometric data;

Savka I.G. – administration of the research, statistical data processing, reviewing and editing of the final text.

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