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PATHOLOGY OF GUNSHOT WOUNDS: CURRENT STATE OF THE PROBLEM

Abstract. Gunshot wounds are one of the most serious problems of modern medicine, as they are characterized by significant destructive tissue damage, high mortality and complexity of treatment. In modern conditions of military conflicts, terrorist threats and increasing crime rates, the number of such wounds is steadily increasing, which requires improving methods of diagnosis, treatment and forensic examination. Gunshot wounds have specific features that depend on the caliber, design of the ammunition, the distance of the shot and the anatomical localization of the wound channel. Not only the issue of surgical treatment of wounds is important, but also the assessment of their consequences, which is important for both clinical medicine and forensic practice. The aim of the study is to analyze the current state of the problem of the pathology of gunshot wounds, including the features of their morphology, mechanisms of tissue damage, complications and approaches to treatment and forensic diagnostics. To achieve this goal, a search for scientific sources was conducted in international and domestic databases that cover the morphological and clinical aspects of gunshot wounds. An analysis of the current literature covering the issues of ballistic trauma, pathophysiological changes in damaged tissues, diagnostic criteria and treatment approaches was performed. The results of the study showed that the morphological features of gunshot wounds largely depend on the kinetic energy of the projectile, its shape and speed. The main lesions include the primary shock wave, the formation of a temporary and permanent cavity, as well as secondary damage due to hydrodynamic impact. It was found that gunshot wounds have a high frequency of complications, including infectious processes, tissue necrosis, impaired regeneration and the development of chronic pain syndrome. Forensic medical examination of these injuries is based on the analysis of macro- and microscopic changes in tissues, which allows to establish the mechanism of injury, the distance of the shot and the type of ammunition. Thus, gunshot wounds remain a complex medical and forensic problem that requires improvement of diagnostic approaches. Modern imaging methods, in particular computed tomography and magnetic resonance imaging, allow for a detailed assessment of the direction of the wound canal, the degree of tissue damage, and the presence of foreign bodies. The use of histological and immunohistochemical

methods contributes to the accurate determination of the nature of the lesion, the characteristics of reparative processes, and the presence of signs of infectious complications. Further research aimed at improving instrumental diagnostic methods will improve the detection of pathomorphological changes.

Keywords: gunshot wounds, pathology, forensic examination, wound ballistics, treatment.

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ПАТОЛОГІЯ ВОГНЕПАЛЬНОЇ РАНИ: СУЧАСНИЙ СТАН ПРОБЛЕМИ

Анотація. Вогнепальні поранення становлять одну з найсерйозніших проблем сучасної медицини, оскільки вони характеризуються значними руйнівними ушкодженнями тканин, високою летальністю та складністю лікування. У сучасних умовах військових конфліктів, терористичних загроз і зростання рівня злочинності кількість таких поранень неухильно збільшується, що вимагає вдосконалення методів діагностики, лікування та судово-медичної експертизи. Вогнепальні ушкодження мають специфічні особливості, які залежать від калібру, конструкції боєприпасу, дистанції пострілу та анатомічної локалізації ранового каналу. Важливим є не лише питання хірургічної обробки ран, а й оцінка їх наслідків, що має значення як для клінічної медицини, так і для судово-медичної практики. Метою дослідження є аналіз сучасного стану проблеми патології вогнепальних поранень, включаючи особливості їх морфології, механізмів ураження тканин, ускладнень та підходів до лікування і судово-медичної діагностики. Для досягнення цієї мети було проведено пошук наукових джерел у міжнародних та вітчизняних базах даних, що висвітлюють морфологічні та клінічні аспекти вогнепальних ран. Виконано аналіз сучасної літератури, що охоплює питання балістичної травми, патофізіологічних змін у пошкоджених тканинах, діагностичних критеріїв та лікувальних підходів. Результати дослідження показали, що морфологічні особливості вогнепальних поранень значною мірою залежать від кінетичної енергії снаряда, його форми та швидкості. Основні ураження включають первинну ударну хвилю, формування тимчасової та постійної порожнини, а також вторинне пошкодження внаслідок гідродинамічного удару. Виявлено, що вогнепальні рани мають високу частоту ускладнень, серед яких інфекційні процеси, некроз тканин, порушення регенерації та розвиток хронічного больового синдрому. Судово-медична експертиза цих ушкоджень базується на аналізі макро- та мікроскопічних змін у тканинах, що дозволяє встановити механізм травми, дистанцію пострілу та

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тип боєприпасу. Таким чином, вогнепальні поранення залишаються складною медичною та судово-медичною проблемою, що вимагає вдосконалення діагностичних підходів. Сучасні методи візуалізації, зокрема комп'ютерна та магнітно-резонансна томографія, дозволяють детально оцінити напрямок ранового каналу, ступінь ушкодження тканин і наявність сторонніх тіл. Використання гістологічних та імуногістохімічних методів сприяє точному визначенню характеру ураження, особливостей репаративних процесів і наявності ознак інфекційного ускладнення. Подальші дослідження у напрямку вдосконалення інструментальних методів діагностики дозволять покращити виявлення патоморфологічних змін.

Ключові слова: вогнепальні поранення, патологія, судово-медична експертиза, ранова балістика, лікування.

Statement of the problem. Gunshot wounds are one of the most serious problems of modern medicine, forensic medicine and pathological anatomy, as they are characterized by a high mortality rate, significant pathomorphological changes and severe consequences even with timely medical intervention. According to the analysis of the German trauma registry, penetrating wounds account for approximately 0.5% of all trauma cases admitted to hospitals, but they demonstrate a high level of complications and mortality. The overall mortality rate among patients with gunshot wounds in Germany reaches 20.4%, which significantly exceeds the mortality rate for other types of injuries [1]. Of particular note are gunshot wounds resulting from mass shootings in civilian environments. In the United States, such incidents result in a high number of victims, and, according to the analysis of mass shootings, 77% of deaths are caused by head and chest injuries, while limb injuries are in most cases non-lethal. An important factor in such cases is the type of weapon, since the use of automatic or semi-automatic small arms significantly increases the lethality rate compared to the use of hand-held firearms [2].

The anatomical localization of a gunshot wound largely determines its consequences and the complexity of treatment. Thus, lesions of the upper extremities, in particular the hand, account for 5% to 10% of all gunshot wounds, but such injuries are often accompanied by severe damage to bone tissue, tendons and nerves, which complicates the restoration of hand function and requires a long rehabilitation period. In 60% of cases of such injuries, patients experience significant loss of function, leading to disability [3].

Injuries caused by shotguns have their own characteristics. According to a large multi-year study in the USA, such injuries account for 15% of all gunshot wounds, and their consequences depend on the distance of the shot and the diameter of the shot. About 40% of patients with gunshot wounds require surgery, and the mortality rate for such injuries is 9%, which is lower than for gunshot wounds but significantly higher than for other types of mechanical trauma [4].

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An additional problem is the residual bullet fragments that can remain in the body after the injury. Studies have noted that about 30% of patients with non-penetrating gunshot wounds have retained bullet fragments in the tissues, which can lead to chronic inflammation, the formation of fibrous capsules, and heavy metal intoxication. In particular, 7% of cases have elevated blood lead levels, requiring long-term observation and possible removal of fragments [5].

The overall incidence of hospitalizations due to gunshot wounds remains consistently high. Between 2004 and 2013, approximately 30,000 hospitalizations related to gunshot wounds were recorded annually in the United States. At the same time, the mortality rate among hospitalized patients was 8.2%, and among patients with penetrating wounds of the chest and abdomen - more than 20% [6].

A separate area of research is cases of self-injury, which constitute a significant proportion of all gunshot injuries. In particular, in the USA, more than 4,000 cases of self-injury are registered annually, of which about 60% are suicidal. The most common localizations of such injuries are the lower extremities, in particular the foot, which is explained by accidental shots while cleaning or carrying weapons [7].

The purpose of the article – to identify and organize current literature data related to gunshot wound pathology.

Research objects and methods. A search for literary sources was performed within the scientometric search databases Scopus, Web of Science and Google Scholar. The search depth was 10 years. To search for the necessary publications, the keywords "gunshot trauma", "pathology", "morphology", "firearm", "wound channel" were used separately and in combinations. The selection criteria were no more than 10 years old, the presence of systematized new data on the features of the pathology of gunshot trauma. Out of 72 publications, 15 were selected for review. PRISMA was used for organization and the PRISMA flow diagram for visualization of the process of selecting publications for review of literary sources in accordance with international standards for writing review articles [8].

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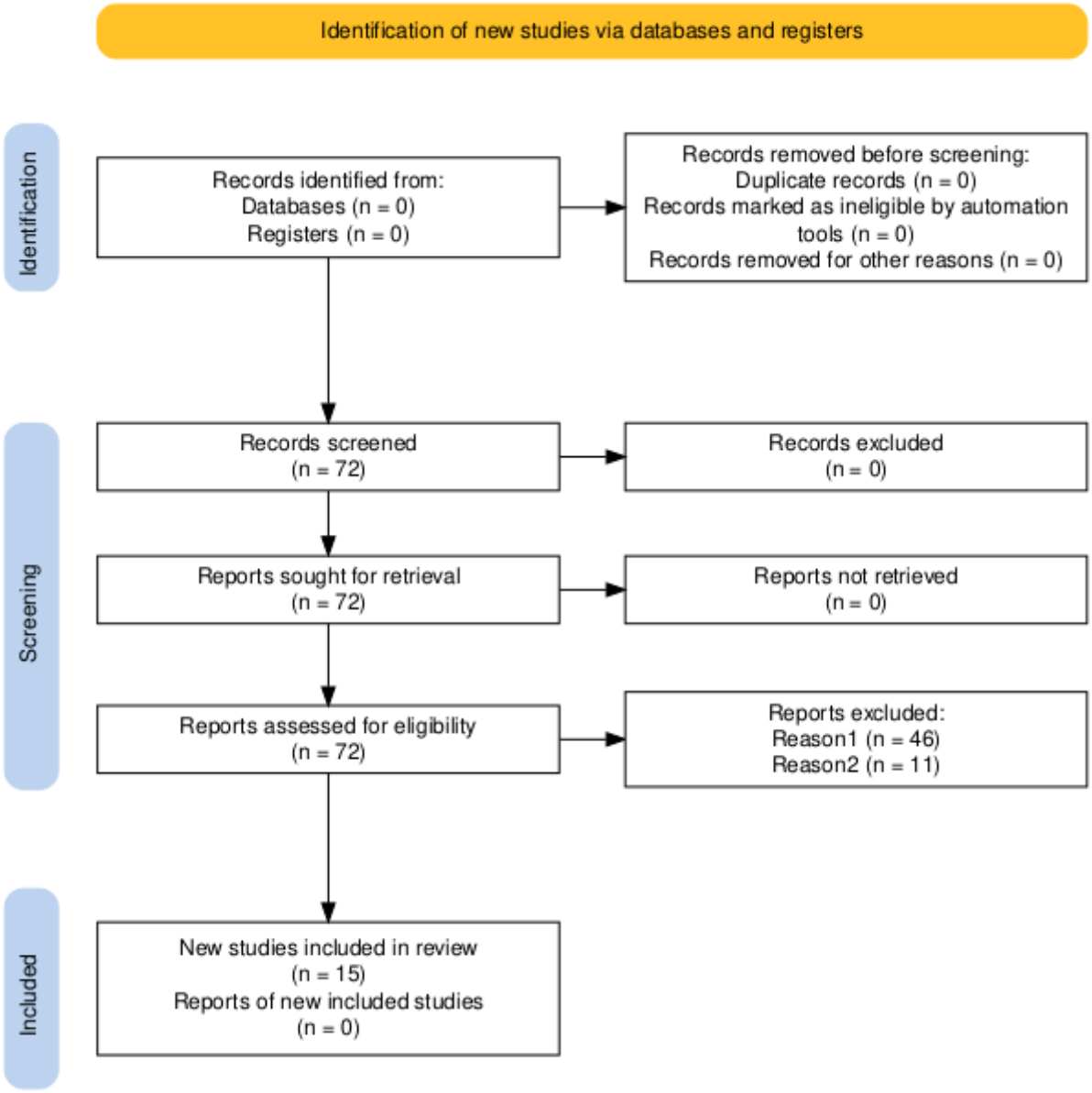

Fig. 1. The PRISMA flow diagram of literary sources search results.

Presentation of the main material.

Research results and their discussion. The morphological features of gunshot wounds are determined by the combination of ballistic characteristics of the projectile, the anatomical structure of the affected tissues and associated factors, such as the angle of entry of the bullet, its speed and the presence of obstacles in the flight path. Research in this area covers a wide range of aspects - from forensic diagnostics of the entrance and exit holes to determining the chemical composition of residual metal fragments in the tissues.

The morphology of gunshot wounds is extremely variable and depends on a number of factors. It has been found that high-velocity penetrating wounds are characterized by significant destructive changes in the surrounding tissues due to the formation of a cavitation cavity, which in some cases is 30–40 times larger than the

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diameter of the bullet itself. At the same time, short-range wounds show significant thermal damage, which can help determine the distance of the shot during forensic examination [9].

Special attention should be paid to the study of the effect of gunshots on textile materials, since this plays a significant role in establishing the distance of the shot and the characteristics of the wound. Gunas et al. conducted a study of the effect of a shot from a Fort-12RM pistol at close range on cotton fabric that imitated the victim's clothing. It was found that characteristic traces of the thermal action of powder gases remain on the fabric, which can be a reliable criterion for differentiating wounds caused by a shot at close range or from a short distance [10]. Another important direction is the study of the chemical composition of metal fragments remaining in tissues after injury. The study by Mikhailenko et al. demonstrated that the use of spectrometric methods allows for high-precision identification of the composition of metal fragments in biological tissues, which is useful for establishing the type of ammunition used. It has been found that residual particles can contain not only lead, but also significant impurities of copper, zinc and antimony, which indicates the type and manufacturer of ammunition [11].

Ballistic aspects of gunshot wounds also play a key role in shaping their morphology. Baum et al. in their review emphasize that at projectile speeds of more than 600 m/s, a significant cavitation cavity is formed, which can exceed the caliber of the bullet by 20–40 times. This leads to ruptures of blood vessels and organs even in tissues remote from the entry site, which complicates surgical treatment and requires special attention in forensic examination [12].

Civilian cases of gunshot wounds have their own characteristics that differ from combat wounds. In civilian settings, the vast majority of injuries are caused by small-caliber weapons, particularly the 9×19 mm Parabellum, which have limited penetration compared to military ammunition. However, even such injuries can cause significant complications, especially if the bullet hits areas with high vascular density or penetrates hollow organs [13].

A detailed analysis of the mechanism of injury from bullets of different calibers was conducted in the study by Stefanopoulos et al. It was demonstrated that small-caliber weapons (e.g., .22 LR) cause relatively small primary injuries, but in some cases lead to significant internal damage due to uncontrolled ricochets of the bullet inside the body. At the same time, large-caliber ammunition (e.g., .45 ACP) cause significantly larger wound channels, although they rarely lead to secondary injuries due to fragmentation [14].

An important issue in forensic examination is the distinction between entry and exit holes, especially in cases of penetrating wounds. It has been established that histological examination can help in this task. Entry holes demonstrate characteristic signs of thermal coagulation, while exit holes have a more discontinuous nature of damage with uneven edges. In 92% of cases, such analysis allows to accurately differentiate the type of hole, which is critically important for forensic examinations [15].

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Thus, the analysis of modern studies demonstrates that the morphology of gunshot wounds is largely determined by the ballistic characteristics of the projectile, as well as the characteristics of the affected tissues. The use of modern research methods, in particular spectrometry and histopathology, significantly expands the capabilities of forensic examination, allowing to establish with high accuracy the characteristics of the wounds, the type of weapon and the distance of the shot.

Conclusions. Gunshot wounds have a complex pathomorphological nature, which is determined by the kinetic energy of the projectile, its shape, speed and angle of penetration. The main morphological manifestations are the formation of a primary zone of necrosis, temporary and permanent cavities, tissue ruptures due to hydrodynamic impact, as well as microscopic changes in the form of localized hemorrhages, vacuolization and destruction of cellular structures. The ballistic features of wounds determine not only the degree of tissue destruction, but also the nature of secondary damage caused by bone fragments or foreign bodies. Analysis of pathomorphological changes in combination with forensic ballistics data allows us to determine the mechanism of wound formation, the distance and direction of the shot, and also to assess the likelihood of complications.

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