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5.1 Structuring features and consequences of combat trauma, infectious complications of wounds and rehabilitation period of servicemen depending on various factors

INTRODUCTION

Relevance of the Problem

In the current conditions of the full-scale war in Ukraine, mine-blast injuries have become one of the most common and severe forms of combat injuries among military personnel. Injuries are classified as isolated, multiple, and combined, depending on the location and nature of the injury. The severity of the injuries depends on the type of weapon, distance from the epicenter of the explosion, the presence of secondary injurious factors and the risk of developing infectious complications. No citizen of Ukraine, regardless of where they live, is immune to the risk of severe combat injuries.

In the first days of the full-scale invasion of Ukraine, 846 cases of civilian deaths or injuries were recorded, of which 44.6% were fatal and 55.4% were injuries. In March 2022, these figures increased 8.6 times, with 58.7% of deaths and 41.2% of injuries. However, in 2023, this level gradually decreased, but the average monthly figure remained critically high: 163 killed and 547 wounded.

The criminal nature of russian troops was manifested not only in mass attacks on the Ukrainian population, but also in the use of phosphorus munitions in March 2022 (Kramatorsk, Kyiv region, and Mariupol). Particularly intense attacks were recorded on the territory of the Azovstal metallurgical plant, and the use of such weapons violates the Geneva Conventions and is classified as a war crime.

The hostilities in Ukraine have shown that combined injuries were most often observed in 47.8% of victims, multiple injuries in 36.1%, and isolated injuries in 16.1%

of cases. Such injuries are extremely complex and require long-term, multidisciplinary treatment and subsequent rehabilitation [225].

Scientists have found that among military personnel, combat trauma is the most common (50.8%) and is the main cause of amputation in 78.4% of cases caused by explosive injuries. In 47.0% of cases, the development of infectious wound complications was recorded, and in 61.0% of them they are polymicrobial, which significantly complicates the treatment of servicemen [190, 210].

The aim of the study was to analyze the scientific sources of domestic and foreign researchers on the characteristics of combat injuries in military personnel, their structure, severity and frequency of infectious complications caused by various types of weapons during a full-scale war in Ukraine and in the world. To analyze the medical records of servicemen for the period of 2023-2024 (n=100), taking into account the following criteria: age, nature of injuries depending on the type of weapon, localization of injuries, complications and the duration of the rehabilitation period.

Research methods: We analyzed more than 104 articles from the scientometric databases Google Scholar, Web of Science, Scopus, PubMed, Science Direct to conduct a retrospective analysis of scientific papers on the etiology, structure and severity of combat wounds, polymicrobial wounds and infectious complications, localization of penetrating neck wounds and the provision of medical care, social and psychological protection. After reviewing the articles and reading their full texts, 74 sources were selected. The depth of the search was for the period 2000-2025. Clinical cases of combat injuries in servicemen who were in the combat zone were reviewed. The following methods were used in the work: bibliosemantic method and content analysis, comparative, systematization of the studied material, statistical, etc.

Key words: military personnel, injuries from various types of weapons, white phosphorus, mine-blast trauma, mechanism of injury, infectious complications, penetrating neck wounds.

5.1.1.1 Modern challenges of military medicine: structure and mechanism of combat wounds depending on location, type of weapon, localization and their infectious complications (literature review)

5.1.1.1.1 Meta-analysis of the structure and mechanism of combat trauma from different types of weapons in Ukraine and in the world

Various weapons, including grenade launchers, small arms, anti-tank guided missile systems, and tactical unmanned aerial systems, result in mine and shrapnel wounds (mechanical injuries), burns, frostbite (thermal injuries), and damage from chemical and phosphorus weapons (structural damage from toxic substances). Biological weapons cause damage from bacterial agents, while weapons of mass destruction lead to reactive/psychogenic states. These are among the most severe injuries encountered during full-scale wars and military conflicts. In today's reality, every Ukrainian, regardless of where they live—whether in Sumy, Zaporizhzhia, Odesa, Kryvyi Rih, Kharkiv, or other nearby settlements in the combat zone or more distant regions—faces the risk of combat injuries, depending on the type and mechanism of injury, or even the threat of death [225, 228].

The severity of injuries from military weapons depends on the type of explosive object (bombs, shells, missiles, grenades, FPV drones (most often during this war), small-caliber ammunition, pyrotechnics, improvised explosive devices, etc.), the amount of explosive substance, as well as the position of the person at the time of the explosion, the distance from the explosion site and the availability of protective equipment. The interaction of these factors determines the overall severity of a serviceman's condition, and their analysis allows us to understand better the specifics of each injury, which is important for timely and effective treatment and rehabilitation of the victims. Today, Ukraine is witnessing an increase in the use of unmanned aerial vehicles (UAVs), which has led to significant changes in the tactics of warfare and the complications of combat trauma. The use of drones has increased the risk of various traumatic injuries due to mechanical contact, explosions or impacts. The main mechanisms of damage to the body when using UAVs include:

Mechanical injuries: UAVs are equipped with rapidly rotating propellers that can cause deep cuts, and injuries to the limbs and face. Such injuries are among the most common among injuries caused by drones; *Impact injuries*: A UAV falling from a height or colliding with a soldier can result in severe bruises, internal injuries, and broken bones, especially when using large or heavy drone models; *Energy impacts:* Damage from explosions or attacks by armed military UAVs can be accompanied by severe injuries, including thermal burns, compartment syndrome, open fractures, and significant blood loss and amputation of limbs [212, 213, 226, 230].

Depending on the type of weapon, several factors of injury simultaneously affect the human body. In case of mine-blast trauma (hereinafter referred to as MBT), the body is affected by a shock wave, high temperature, flame, toxic effects of gaseous explosion products, resulting in mechanical trauma (due to impacts on various objects located nearby), barotrauma, and acoustic trauma [184, 208].

In gunshot wounds, the human body is affected by the direct action of the projectile, the main shock wave (which includes the effect of direct impact and air compression), the lateral shock wave (which creates a temporary pulsating cavity), the vortex trail (airflow, as well as the flow of tissue particles behind the projectile).

The detonation of an anti-personnel mine (APM) results in a complex impact on the human body caused by mechanical, thermal and chemical factors. One of the key damaging agents is the shock wave generated during the explosion, which can cause severe traumatic injuries. An additional damaging effect is caused by the flying of shrapnel and secondary fragments resulting from the explosion. Psychological and neurophysiological consequences are also important. One of the most common disorders is post-traumatic stress disorder (hereinafter referred to as PTSD), which is accompanied by sleep disturbances, anxiety, and cognitive dysfunction. Other acute neurological disorders include disorientation, memory impairment, and decreased concentration.

A blast wave has a complex and multifactorial effect on the central nervous system, initiating several pathological processes. One of the key mechanisms of its action is the disruption of the blood-brain barrier (BBB), which is a highly selective physiological barrier between the systemic circulation and neurons. Blood-brain barrier destabilization leads to uncontrolled penetration of plasma components into the brain parenchyma, which activates neuroinflammatory processes and neuronal damage. BBB dysfunction is accompanied by destabilization of cerebral hemodynamics, changes in cerebral perfusion pressure, and a decrease in cerebral blood flow. This leads to the development of ischemic conditions and hypoxia of brain tissue, which is an important pathogenetic factor in the development of cognitive and behavioral disorders. Delayed neurodegeneration and oxidative stress can exacerbate these pathological changes, contributing to the formation of chronic neurophysiological disorders that require a multidisciplinary approach to the diagnosis, treatment, and rehabilitation of military personnel [189, 218, 231].

A clinical and epidemiological analysis conducted by Khomenko I., Korol S. and others (2020) for the period 2014-2019 showed that among servicemen involved in combat operations during the ATO/JFO, the most common types of combat injuries were shrapnel wounds (33.5%-70.3%), MBTs (12.2%-50.8%) and bullet wounds (9.1%-15.6%). The analysis of the localization of combat injuries showed that the dominant injuries were those of the extremities, which accounted for 62.6% of the total number of injuries, including 36.9% of the lower extremities and 25.7% of the upper extremities. The share of craniocerebral injuries was 31.9%, chest injuries - 11.7%, and combined injuries - 22.7%. In the structure of combat sanitary losses, the proportion of limb injuries ranged from 52.3% to 60.1%, with 32.5% to 39.8% of cases diagnosed with fractures of long bones, accompanied by damage to soft tissues, major vessels and nervous structures. An analysis of the nature of combat injuries shows the prevalence of combined injuries (48.9%), multiple injuries were recorded in 34.3% of cases, while isolated injuries were much less common - 16.8% [223].

According to a study by researcher Bespalenko A. (2020), conducted among hospitalized ATO/JFO participants at the Military Medical Clinical Center for Occupational Pathology of the Armed Forces of Ukraine, the main causes of limb amputations were MBTs, which accounted for 78.4% of the total number of cases. Explosive injuries without the involvement of mines caused 11.7% of amputations, while gunshot wounds caused amputations in 5.9% of patients. In terms of the number of limbs lost, the majority of victims (84.3%) had one limb amputated. Amputation of two limbs was observed in 13.7% of cases, while 2.0% of patients suffered the loss of three limbs. Upper limb amputations were observed in 9.8% of patients, and in 60.0% of them the amputation was performed at the level of the lower third of the forearm. As for lower limb amputations, 90.2% of patients suffered them, of which 69.0% had amputations below the knee joint [210].

Injuries caused by modern firearms during a full-scale war are characterized by specific features, namely significant tissue damage along the wound channel and a high incidence of multiple and combined injuries. According to a study by scientists, in the first days of the large-scale invasion of Ukraine, the most common types of injuries were injuries to the limbs and pelvic bones (43.7%), chest (20.5%), head and neck (17.9%), and abdomen and pelvis (12.6%). Multiple injuries were observed in 39.3% of cases [214, 217, 227].

According to the analysis of the structure and mechanism of combat trauma by scientists around the world during the US military operations in Iraq and Afghanistan, the most common injuries were lower limb injuries - 19.8%, open wounds - 18.8%, chest and/or abdominal injuries - 17.7%, traumatic brain injuries - 14.2%, and burns - 7.4% [169].

According to D'Souza E.W. (2022), Belmont P.J. (2016), during the US military conflict in Iraq and Afghanistan, lower extremity injuries accounted for 19.8%, open wounds 18.8%, chest or abdominal injuries 17.7%, traumatic brain injury 14.2%, and burns 7.4%. Injuries caused by combat-related injuries accounted for 81.0%, including 73.0% of musculoskeletal injuries; 16.0% of orthopedic injuries from firearms; the total percentage of deaths was 3.2% [162, 169].

According to DePalma RG. (2015), Agoston D.V. (2015), Zhu X (2024), it was found that traumatic brain injury (hereinafter - TBI) associated with thermobaric explosives (detonation of a salvo can affect up to 300 people) is a destructive weapon and a cause of severe TBI (long-term and neuropsychological consequences) and a high number of fatalities. During the military conflicts in Afghanistan and Iraq, 15.0%

to 30.0% of injuries were diagnosed with TBI. In 80.0% of the injuries sustained during the military conflict, explosives caused 5.0% of severe injuries, 10.0% of moderate injuries, and the rest of the injuries were mild. Among the wounded, 60.0% to 80.0% sustained seismic penetrating wounds to the head, limbs and torso. Components of combat/psychological stress were noted in servicemen with mild TBI [158, 170, 209].

Research by Smith J. (2019), Meister M. (2023) found that in combat conditions, 11.0%-11.3% of servicemen were diagnosed with an open penetrating skull injury, with CNS infection developing as a complication, requiring invasive neurosurgical methods. Primary explosive injury causes a combination of mechanical/barotraumatic changes that lead to the development of ischemic processes, cerebral edema, and the creation of favorable conditions for the penetration of pathogenic microorganisms, which is confirmed by the study. The study also revealed a high incidence of complications, such as meningitis, encephalitis, and brain abscess. Treatment of such conditions requires an integrated approach (craniotomy, wound debridement, necrectomy, antibiotic therapy taking into account pathogen resistance and intensive care) [184, 195].

A retrospective analysis by Garcia A. (1999-2019) of vascular injuries of the extremities in military personnel during the conflict in Colombia showed that 63.0% of gunshot wounds caused vascular injuries. In 10.0% of these cases, amputation was necessary. The main causes of amputation were compartment syndrome (7.0%), femoropopliteal injuries (2.6%), and associated fractures (3.2%) [172].

During the armed conflict in Gaza, UAV strikes were the leading cause of amputations among explosive weapons victims, according to a study by Heszlein-Lossius H. (2019, 2020). Specifically, 54.0% of amputations were caused by drone strikes, while tank-related explosions accounted for 11.0% of amputation injuries. Patients who sustained amputations as a result of UAV attacks required more surgical interventions compared to those affected by other types of explosive weapons, indicating the more severe nature of the injuries [177, 178].

Explosions of APMs often cause both full and partial amputations of limbs. The shock wave generated by the explosion penetrates soft tissue, sending fragments of metal or plastic from the mine body to the lower extremities. This leads to significant damage to blood vessels and nerve structures. According to the research of scientists Trykhlib V. (2015), Sharrock A. (2019) and Vuoncino M. (2020), the majority of vascular injuries to the lower extremities during hostilities are caused by explosive mechanisms, which most often affect the vessels in the tibia. Such injuries significantly complicate the possibility of preserving the limb in the long term compared to gunshot wounds [196, 205, 219].

5.1.1.2 Analysis of wound features depending on the location of the person at the time of the explosion from different types of weapons

The injuries caused by the explosion of an APM, according to Gordon W. (2018), Guriev S. O. (2020), are divided into three main types, depending on the blast effect and shrapnel formation. In cases of direct contact with an explosive device, traumatic amputations or significant damage to anatomical structures that were in the detonation zone are most often diagnosed. In addition, the risk of concomitant damage to the contralateral lower limb, pelvic organs, perineum, and abdominal structures increases. If the explosion of an APM occurs accidentally or the device is held in the hands, the nature of the injuries is determined by the distance to the epicenter of detonation. If an explosive device detonates directly in the hands of the victim, the upper torso, face and upper extremities are most often injured. The severity of the injuries also correlates with the presence of protective equipment, and anthropometric parameters of the soldier, including body weight and length of the lower limbs. Studies have shown that servicemen with longer lower limbs have a lower risk of traumatic amputations, as the increased distance between the epicenter of the explosion and the center of body mass contributes to a partial reduction in the force of the explosive impact [173, 174].

The severity of injuries among servicemen depends on a number of factors, including the force of the explosion, the distance from the detonation epicenter, as well as the direction of the airwave and sound pulse, the area of the potential impact site, and the number of servicemen in the epicenter. In the structure of injuries, 6.8% of cases of ruptures of parenchymal organs, such as the spleen and liver, were found to be caused by the blast wave. In addition, shrapnel wounds of the anterior abdominal wall, as well as blunt and crush injuries were observed. Injuries to the abdomen and chest were less common among military personnel compared to civilians, which can be explained by the use of protective equipment, including bulletproof vests. Explosive force parameters (explosive pressure, time duration, impulse, fragments and toxic gaseous products: aerosols (dust, smoke) carbon dioxide, carbon monoxide, carbon (soot)), and distance from the epicenter affect the severity of the injury. Soldiers who are between the source of the explosion and the building suffer injuries that are two to three times more severe than those of soldiers in the open. In real conditions, the blast wave reflects from the ground surface, forming reflective waves that change its parameters and configuration. When space is enclosed (building, vehicle), the blast wave interacts with the surrounding structures and creates secondary reflections. They are superimposed on the primary blast front and create a multicomponent wave structure that enhances the damaging effect on the body [167, 192, 197].

5.1.1.3 Retrospective analysis of the effects of exposure to phosphorus weapons in military personnel: pathogenesis of damages and clinical manifestations

The use of white phosphorus (WP) as a munition dates back to the nineteenth century, when Irish nationalists used it in the form of the so-called “Fenian fire”. Historical data shows that the use of WP shells, like other types of weapons, leads to severe traumatic consequences for both civilians and military personnel. According to a study by Barillo D., Cancio L. (2004), chemical burns accounted for 2.1% of all hospitalizations in the period 1969-1985 and 1986-2000. Over the 19 years of observation, the average area of skin damage was 19.5%, while over the next 15 years this figure decreased to 8.6%. At the same time, the mortality rate increased from 5.4% to 13.8% in the comparable periods. The average length of hospitalization decreased from 90 to 15 days. In 146 cases analyzed, the chemical agent responsible for the injuries was WP [163].

WP has several hazardous properties. It is a highly reactive substance that spontaneously combusts on contact with air, forming toxic phosphorus oxides. Interaction with strong alkalis leads to the release of phosphine, a poisonous gas that is dangerous to humans. In addition, it actively reacts with oxidizing agents, halogens, nitrites, sulfur, and metals, which can cause explosions and intense fires. WP can spontaneously combust at room temperature in the form of particles, which increases the risk of fires/burns. In certain cases, phosphorus munitions may contain radioactive substances, which increases the potential threat of radiation contamination of the environment.

The armed conflict in Ukraine has caused significant degradation of ecosystems, leading to a deterioration in the sanitary and hygienic characteristics of water resources, air and soil cover. Since the outbreak of full-scale hostilities, there has been an increase in the level of environmental pollution by toxic substances, including chemical and phosphorus weapons prohibited by the Geneva Convention. The use of such weapons poses serious environmental threats with unpredictable consequences for the environment and significantly increases risks to public health [211, 216, 229].

From February 2023 to September 2024, 4228 cases of the use of toxic chemicals (chlorpicrin) by the enemy were recorded in Ukraine. During this period, 2,058 servicemen of the Armed Forces of Ukraine applied to medical institutions with symptoms of chemical damage of varying severity caused by the use of chemical warfare agents of irritant action (sternites and lacrimators). The most commonly used chemical munitions were K-51 grenades containing chloropicrin (PS) and 2-chlorobenzalmonononitrile (CS), RGR grenades with CS, and RG-VO grenades (862-3-23) with chloroacetophenone (CN). The damage caused by these substances was classified into three severity levels, and they affected the eyes, skin, and in some cases respiratory and cardiac paralysis and death. The Armed Forces of the russian federation (December 2023) for the first time used new gas grenades with chloroacetophenone as an active component against the personnel of the Armed Forces of Ukraine. The toxic dose of this substance is 11 mg-min/l (high toxicity). To achieve a lethal effect, 70 drops of the chemical are sufficient, which poses a threat to the life of a serviceman [220, 221].

The toxic effects of WP are combined, caused by local and systemic effects. Upon contact with the skin, the substance penetrates deep tissues, causing chemical burns, necrosis, and vascular damage, which may be accompanied by internal bleeding and multiple organ failure. Inhalation of WP during combustion irritates the mucous membranes of the respiratory tract, pulmonary edema, bronchospasm, and acute respiratory distress syndrome (ARDS). Prolonged exposure to toxic aerosols can lead to chronic respiratory damage and respiratory failure. During an explosion, WP particles can penetrate open wounds, causing deep chemical burns that are difficult to treat due to the prolonged burning of phosphorus, even in the absence of oxygen. The absorption of phosphorus into the bloodstream leads to systemic poisoning, metabolic acidosis, and damage to the liver, kidneys, heart muscle, and central nervous system. Phosphorus munitions are actively used in combat situations, but their use leads to severe physical injuries and post-traumatic psychological disorders.

According to a study by Brutyan S. (2021), conducted during the Nagorno-Karabakh conflict of 2020, the average area of affected body parts due to exposure to WP was 14.1%. The highest incidence of injuries was recorded in the head and neck (79.3%), upper limbs and hands (90.2%), while the torso was affected in 26.8% of cases and the lower limbs in 46.3%. Injuries to the visual organs, including the eyes and eyelids, were observed in 20.7% of patients. Injuries to the upper respiratory tract were detected in 30.5% of cases, damage to the external ear and ear canal in 50%, and damage to the lung tissue in 15.9% of the victims. In addition to burn injuries, 37.9% of patients had multiple shrapnel wounds. Among the victims with severe burns, 28.7% required intensive care, of whom 10.3% died during the first week of hospitalization [164].

Phosphorus munitions, in particular, WP, are known for their high effectiveness in combat operations but also cause serious injuries, both traumatic and post-traumatic psychological changes. WP (bomb explosion) causes burns to the soft tissues of the human body when in contact with burning material, as well as burns to the upper respiratory tract through inhalation of smoke or gases released during combustion. A study by Khurshid et al. (2022) found that contact with phosphorus shells led to a variety of psychological injuries, including insomnia in the first days, fatigue and stress, fear of noise; traumatic brain injuries, and head injuries [180, 229].

Xie W.G. (2008) found an average burn rate of 9.0% from the yellow phosphorus explosion, with the average area of II B and III-degree burns being 7.0%. The majority of patients had symptoms and signs of phosphorus poisoning, 33.0% had liver dysfunction, 18.5% had kidney damage, and 52.0% had electrolyte imbalance [207].

Scientist Lakota J. (2023) describes the pathophysiological explanation of hypocalcemia: phosphoric acid (H_3PO_4) is the end product of the reaction of phosphorus pentoxide P_4O_{10} (empirical formula P_2O_5) with water (H_2O). Calcium (or magnesium) is used to “neutralize” the phosphoric acid. The end product - calcium (magnesium) salts of phosphoric acid - are very poorly soluble in water. However, the only source of calcium (magnesium) is “free” calcium (magnesium) in the blood plasma of military personnel. That is, the drop in calcium ions reflects the amount of this ion that was needed to neutralize phosphoric acid. Calcemia and phosphatemia in the blood of military personnel reflect the “amount” of “burned” phosphorus [183].

Rapid development of hypocalcemia and hyperphosphatemia cause the development of cardiac arrhythmias in patients with abnormalities after burns. The abnormalities are manifested by prolongation of the QT interval, changes in the ST-T wave, and progressive bradycardia. In addition, the scientist recorded early metabolic changes due to the effect of WP on the patient's body [168].

Austin E.B. (2016) points out that absorbed phosphorus can cause intoxication of many organs. In the central nervous system, intoxication manifestations include psychosis, delirium, convulsions, or coma. Symptoms of gastrointestinal damage include abdominal colic, melena, hepatomegaly, and jaundice. The urinary system also has changes: proteinuria and acute tubular necrosis of the kidney. The cardiovascular system also undergoes changes: ventricular extrasystole and myocarditis are present.

The blood composition changes, as thrombocytopenia and hypoprothrombinemia are observed [159].

5.1.1.4 Comprehensive meta-analysis of penetrating neck wounds in the world and Ukraine during military conflicts

Penetrating wounds of the neck are a complex clinical problem due to the presence of numerous vital anatomical structures in an area with limited soft tissue protection. Despite their relatively low incidence, such injuries pose a significant risk, as they can affect the airways, major vessels, gastrointestinal tract, and nervous system, often in combination. Ensuring effective treatment of these injuries is challenging, especially in pre-hospital settings with limited medical resources, as well as in remote areas where access to proper medical care is limited. Surgical tactics for penetrating neck injuries are based on a detailed assessment of the location and nature of the injuries, the development of complications and the risk of mortality. The main goals of treatment are to restore airway patency, ensure unimpeded enteral nutrition, and use reliable methods of wound closure to prevent digestive tract failure and ensure the stability of the laryngotracheal framework and aerostasis [227].

It was reported that the mechanism of penetrating neck injury was blast trauma in 73.0% of patients and gunshot wounds in 27.0%. Cervical spine injuries, including fractures and spinal cord injuries, were diagnosed in 22.0% of the victims. However, the survival rate before hospitalization remained critically low and amounted to only 7.0%. Among those hospitalized, 2.0% died within the first 72 hours due to the severity of their injuries. Only 1.8% of patients who reached the surgical facility alive were diagnosed with an unstable cervical spine injury that required surgical stabilization, but later died as a result of severe concomitant severe TBI [193].

Penetrating ballistic wounds of the neck are characterized by a high mortality rate. The data obtained by Ramasamy A. (2009), Krausz A. (2015) indicate that the probability of developing an unstable cervical spine injury in patients who survive such injuries remains extremely low. In dangerous environments, such as terrorist attacks, military conflicts, or mass shooting incidents, the risk associated with delaying the provision of necessary care due to the obligation to immobilize the cervical spine outweighs the potential benefits of its use [181, 193].

Penetrating neck wounds during the military conflicts in Iraq and Afghanistan ranged from 4.9% to 10.0% of all combat wounds, of which up to 41.0% were accompanied by damage to the great vessels. The main causes of mortality in such injuries were critical bleeding, respiratory tract damage, and spinal cord injury, which accounted for 28.0% of deaths. The high risk of death is due to the anatomical complexity of the neck, as well as difficulties in ensuring adequate airway patency. The researcher Aljanoubi M. (2024) draws attention to the importance of rapid restoration of airway patency in patients with penetrating neck wounds, especially in associated cardiac arrest. The study emphasizes that the techniques (coniotyroidectomy and tracheotomy) are vital to ensure ventilation and improve survival. It is also important to train medical personnel in emergency anterior airway access techniques and to develop standardized allergy algorithms for providing care in combat [160].

The United States and the United Kingdom have demonstrated differences in their approaches to surgical training and the organization of medical care in deployed medical treatment facilities (MTFs) to support military operations in Iraq and Afghanistan.

The study by Breeze J. (2020) analyzed cases of traumatic facial injuries among injured servicemen during combat operations in Iraq and Afghanistan. The purpose of the study was to assess the frequency and types of injuries, as well as to compare treatment methods in US and UK military medical facilities. The most prevalent injuries were soft tissue injuries (64.0%), fractures of the facial skeleton (36.0%), inner and middle ear injuries (28.0%), and other head and neck injuries (11.0%). Penetrating wounds to the neck were mostly caused by 58.0% of explosive weapons and 36.0% by firearms. The main types of injuries were 74.0% soft tissue damage, 25.0% damage to the main vessels, of which 46.0% was to the carotid artery, and damage to the airways, including 14.0% of the larynx and trachea [165].

According to a study by Breeze J. (2020), neck injuries were recorded in 4.9% of injured servicemen, of which the vast majority (83.0%) had penetrating injuries, while the rest had blunt trauma. After taking into account fatalities on the battlefield, the incidence of neck injuries increased to 10.0%. Patients with neck injuries who underwent a specialized neck examination accounted for 32.0%; patients with damage to the main vessels of the neck - 21.0%, patients who underwent procedures for ligation or restoration of vessels - 41.0%. It was found that penetrating neck wounds were the direct cause of death in 28.0% of cases where this factor was recorded [165].

A retrospective analysis of data for 2015-2019, conducted during the military conflict in Syria, found that penetrating wounds were the leading mechanism of traumatic neck injuries. The main sources of shrapnel wounds were explosions (83.0%) and firearms (17.0%). Fractures of the bones of the facial skeleton were diagnosed in 32.0% of the victims, most often affecting the maxillary bone (28.4%), orbital bones (22.0%) and teeth (18.5%) Primary reconstructive interventions were performed in 49.0% of cases, while secondary surgical interventions were performed in 8.0% [191, 204].

In a retrospective analysis conducted by Benov A. (2019), Tsur A.M. (2021), the nature of injuries sustained by military personnel during hostilities in Syria and Israel was investigated. One of the main goals was to identify the most common mechanisms of injury and to evaluate the effective prehospital measures implemented by the Israeli Defense Forces Medical Corps (IDF-MC). The results of the analysis showed that 54.0% were penetrating wounds to the neck and chest, with shrapnel accounting for the majority of cases up to 68.0%. Prehospital rescue measures included intensive care with the use of modern hemostatic support (fresh dried plasma up to 7.0% and tranexamic acid 15.0%) and restoration of airway permeability [166, 201].

According to a 20-year retrospective analysis by Tsur N. (2020), neck injuries are a significant cause of mortality and morbidity among Israeli soldiers during combat operations. During the study period, it was recorded that 1.0% were isolated neck injuries, while 94.0% of cases were injuries without neck damage. At the same time, 42.0% of neck injuries were classified as urgent, requiring urgent medical and diagnostic measures [202].

The most vital life-saving first aid measures were to restore airway patency and stabilize hemodynamics. Extended airway intervention was performed in 12.0% of patients with neck injuries, which is significantly higher than the corresponding rate in the group of patients without neck injuries, which was 3.0% [161].

The analysis of gunshot wounds, MBT, as well as primary and secondary mortality rates from penetrating neck injuries during the military conflict in Ukraine became the basis for a strategic reassessment of approaches to medical care by the German Armed Forces. The experience gained by Ukrainian surgeons has significantly influenced the tactics of surgical treatment of combat injuries during military conflicts due to the modernization of military weapons and changes in the nature of combat injuries. The main causes of primary mortality in combat injuries were: TBI, and massive bleeding from thoracoabdominal injuries. Secondary mortality was caused by: torso and neck injuries, and burns caused by chemical and phosphorus weapons [206].

According to the study by Gybalo R.V. (2022), a 33-year-old serviceman who sustained a gunshot wound during hostilities in the Kyiv region (Ukraine) is described in a clinical case. The bullet passed through the left axillary region of the chest and the left upper extremity. The physical examination revealed multiple wounds, including entry and exit wounds in the chest and shoulder. An X-ray examination confirmed the presence of a foreign body (metal fragment) in the projection of the first left rib, located behind the left clavicle close to the left common carotid artery and internal jugular vein. During surgery, a 25 mm retained bullet was found in the space between the common carotid artery and the jugular vein [175].

This clinical case confirms that bullets or projectile fragments can remain undiagnosed for a long time and be discovered by chance, even in the absence of clinical symptoms, which is consistent with other studies. Gunshot wounds are often characterized by an unpredictable trajectory, so CT or radiography is recommended for all wounded to detect foreign bodies in a timely manner and prevent complications. According to a study by Benov A. (2019), effective prehospital care in combat situations includes the application of tourniquets, the use of tranexamic acid to control bleeding and ensure airway patency (endotracheal intubation, cricothyroidotomy). The introduction of these methods is critical to improving tactical medicine in combat conditions [166].

The study by Simpson C. (2021) conducted a systematic review of the literature to assess current approaches that highlight the features of prehospital treatment of penetrating neck wounds before transporting victims to the emergency department. The results of the analysis are presented according to the "cABCD" principle (catastrophic bleeding, airway, breathing, circulation), which helps to standardize patient assessment and prehospital treatment, facilitating the application of care protocols for clinicians. The main cause of complications and mortality in head and neck injuries is uncontrolled/critical bleeding, most of which occurs in the prehospital stage of care. Neck wounds belong to the category of injuries for which the use of tourniquets/tourniquets is impossible. The traditional method of stopping bleeding is to apply direct pressure to the wound. Recently, hemostatic dressings have been widely used, which contain actinic substances that stimulate blood clotting and help stop bleeding. According to the results of studies, the use of such dressings at the prehospital stage allows achieving effective hemostasis in 67.0-100% of cases, with an average success rate of 90.5% [198].

Hemostatic dressings, such as QuickClot® Combat Gauze™ (predominantly used in the U.S. military) and Celox™ (widely used in the United Kingdom), have demonstrated a significant advantage over standard gauze in terms of bleeding control. Studies confirm that these products provide bleeding control in more than 88.0% of cases, with no side effects reported. In cases of penetrating neck wounds, the practical use of hemostatic dressings involves careful tamping of the wound channel to maximize hemostasis.

The key components of prehospital care are the use of tranexamic acid and lyophilized plasma. Tranexamic acid, administered to servicemen at high risk of bleeding, helped reduce the volume of blood loss and minimized the need for further resuscitation. Lyophilized plasma, which was used as the main means for rapid correction of hemodynamic disorders, effectively restored circulating blood volume, prevented the development of hypotension, and improved the survival chances of servicemen with critical combat injuries [176, 188, 227].

5.1.1.5 Meta-analysis of the etiopathogenesis and prevention of infectious complications in injuries with different types of weapons

The most common injury on the battlefield is limb trauma, often accompanied by infection. Amputations, open fractures, or deep open wounds were observed in 16.0% of wounded soldiers. At the same time, in 47.0% of cases, soft tissue injuries of the extremities were complicated by infection, which required timely surgical intervention and antibiotic therapy to prevent complications [190].

According to Stewart L. (2019), Tribble D.R. (2019), the analysis of the structure of traumatic injuries sustained as a result of combat operations in Iraq and Afghanistan (2009-2012) was as follows: 31.0% of servicemen had one amputation, 36.0% had open fractures, and 33.0% had open soft tissue wounds. During the initial hospitalization, 34.0% of U.S. servicemen and women were diagnosed with infectious skin and soft tissue infections. At the same time, 38.0% of patients receiving primary care developed a new infection [199, 203].

During the war conflicts in Iraq and Afghanistan, according to Mende K. (2022), there was an increase in the number of servicemen with polymicrobial wounds and infectious complications associated with combat trauma. In order to improve treatment, a large number of studies have been conducted to investigate the etiology of wound infections. Gram-negative bacteria were detected in 12.0% of the victims, while in 61.0% the microflora was polymicrobial, including both Gram-negative and Gram-positive bacteria (E. Coli, Enterococcus spp.), and yeast [185].

According to Heitkamp R. (2018), severe combat wounds of the extremities accounted for 91.0%, with one to three polymicrobial infections detected in the majority of servicemen, and 60.0% had three or more. The most frequent Enterococcus spp was localized in the thigh area. The dominant species among the representatives of this genus was Enterococcus faecium, isolated in 66.0% of group infections and 74.0% of polymicrobial infections. Frequent colonizing microbes in Enterococcus-associated polymicrobial wound infections in 64.0% of cases were pathogens of the ESKAPE group - highly antibiotic-resistant microorganisms, the presence of which complicates the course of the infectious process and the choice of effective antimicrobial therapy. The most common pathogens that were sown in combat wounds were: Enterococcus faecium - a pathogen that causes severe urinary tract infections, sepsis and endocarditis, Staphylococcus aureus - which causes a wide range of infections (pneumonia, osteomyelitis), Klebsiella pneumoniae - an enterobacterium is a common cause of pneumonia, sepsis, and urinary tract infections, Acinetobacter baumannii is a pathogen associated with wound infections, sepsis, and pneumonia, Pseudomonas aeruginosa causes respiratory tract and skin infections, Enterobacter spp. - causes infections of the gastrointestinal tract and urinary system. In 35.0% of cases, fungi were detected, which further complicated the course of the wound process [179].

The study by McDonald J. (2022) investigated the effects of combat injuries and related infections in the TIDOS (Traumatic Infectious Diseases in Trauma) program. Among the participants, 91.0% received medical care through the VA health care system, but only 47.0% of patients agreed to follow-up. New infections were diagnosed in 38.0% of patients after discharge from the hospital. As a result of cooperation with the U.S. Department of Defense, it was found that 71.0% of infections were detected through military medical records. Among patients with genitourinary trauma, sexual dysfunction was observed in 36.0%, urinary tract infections in 21.0%, urinary retention or incontinence in 14.0%, and urethral stricture in 8.0%. Further research includes estimating the incidence of osteomyelitis among servicemen and women with amputations and open fractures, the impact of injuries on mental/mental health and social factors, and an analysis of the economic costs and accessibility of medical care for infectious complications [186].

The study by Rodriguez R.C. (2022) analyzed an outbreak of invasive fungal wound infections that occurred among military personnel with blast injuries during an operation in Afghanistan. Among the wounded who were hospitalized in medical facilities, 13.0% met the criteria for IFI, and 8.0% had a high degree of probability of infection [194].

A study conducted by Murray C. K. (2008) included an analysis of wounded military personnel with colonization and infection (multidrug-resistant). During hospitalization, 12.0% of patients had colonization with multidrug-resistant gram-negative bacteria. Among combat casualties who were hospitalized, 27.0% were diagnosed with multidrug-resistant gram-negative bacterial infections. The analysis of combat-related wounds showed that 61.0% of confirmed limb infections were polymicrobial in nature (a combination of gram-negative and gram-positive bacteria, yeast, fungi and anaerobic microorganisms). During clinical examinations, Escherichia coli was most often identified as the causative agent of colonization with multidrug-resistant strains, namely those that produce extended-spectrum β-lactamases. Enterococcus spp. were detected in (53.0%) of wound infections, which were often associated with severe injuries and amputations. The role of biofilms in the wound healing process was also assessed, and it was found that their formation increases the risk of recurrent bacterial seeding (97.0% vs. 59.0% in cases without recurrence). Data on the microbial threats associated with combat wound infections contribute to the improvement of treatment and prevention of infectious complications in military personnel [187].

According to Stepanskyi D. (2024), and Franke A. (2024), the risk of infectious complications in servicemen with combat injuries increases due to long-term evacuation, overcrowding in hospitals, and limited resources for infection control. Prolonged transportation of patients contributes to colonization with multidrug-resistant bacteria, which complicates treatment and worsens prognosis. A study conducted in Dnipro, Ukraine showed a high level of multidrug resistance among isolated pathogens from combat wounds, which complicates the selection of antibiotic therapy. An analysis of patients evacuated to European clinics revealed a high frequency of polymicrobial infections, including gram-positive and gram-negative bacteria and fungi. This emphasizes the importance of improving infection control strategies and antibiotic therapy [171, 200].

The data of Kryshevskyi Y. (2020) and Khomenko I. (2018), obtained in the periods of 2014-2018 ATO and 2018-2020 JFO, showed that the frequency of purulent-septic complications of gunshot wounds among servicemen was 50.0%-75.0%. The microbiological analysis of these complications indicates the prevalence of microorganisms with a high level of resistance to antibacterial agents, which significantly complicates the choice of therapy. The persistence of resistant microorganisms contributed to a prolonged course of the infectious process, which led to prolonged wound healing and increased hospitalization. The results emphasize the need to improve antibiotic therapy, strengthen effective infection control measures, and develop effective strategies for the prevention of infectious complications in medicine [215, 224].

During the 2014 ATO/JFO in Ukraine, a study conducted by Kovalchuk V. (2017) among military personnel found that 87.7% of microbiological cultures had a single microorganism, while 12.3% had polymicrobial infections. Among all isolated microorganisms, 65.0% were gram-negative rods, 22.2% were gram-positive cocci, and 12.8% were gram-positive bacilli. The most common microbial mixture was Acinetobacter baumannii with Enterobacteriaceae or other non-enzymatic gram-negative bacilli together with Enterococcus spp. In the first week after the injury, gram-positive microbes with low pathogenicity predominated, but in the process of wound healing, an increase in gram-negative bacilli (Acinetobacter) was observed, indicating a dynamic change and the need to adapt approaches to antibiotic therapy [182].

The research of Fomin O. (2023) shows that bacterial contamination of combat wounds has characteristic patterns of change depending on the different stages of treatment. Primary wound contamination occurs due to microorganisms of soil origin (Bacillus spp., non-spore-forming anaerobes) and gram-positive aerobes, which are usually not the main causative agents of purulent-septic complications. However, untimely provision of medical care, as well as the multi-stage evacuation of servicemen through various medical facilities, increase the risk of secondary infection with hospital-acquired strains of bacteria with multiple antibiotic resistance. The microbiological analysis of gunshot and mine-blast wounds of servicemen conducted as part of this study confirms the prevalence of gram-negative bacteria in combat wounds, which has a high risk of nosocomial infections [222].

5.1.2. Scientific rationale and description of the research work

We analyzed the medical records of servicemen for the period 2023-2024 (n=100), taking into account the following criteria: age, nature of injuries depending on the type of weapon, localization of injuries, complications, and the duration of the rehabilitation period.

According to the study, among the servicemen, 43.0% were under the age of 30, 41.0% were aged 30-40, while 16.0% were aged 40-50, and the sample included only men (Fig. 1).

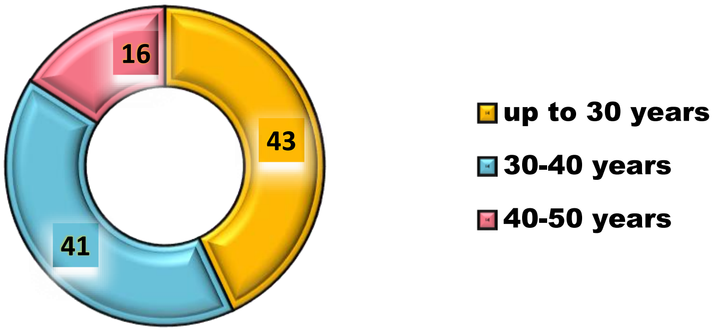

Fig. 1 Age distribution among military personnel, %.

According to the results of the study, in a full-scale war in Ukraine, explosive weapons dominate, which significantly affects the nature and severity of injuries. It has been established that the main cause of MBT is artillery shells, which account for 45.0% of the total number of injuries among military personnel. At the same time, the study showed a significant increase in the impact of modern high-precision weapons, in particular FPV drones, which caused 36.0% of combat injuries, indicating a trend toward the use of remotely controlled weapons in combat operations in a full-scale war. The remaining 19.0% of injuries were caused by APMs, which indicates a high threat in the combat zone (Fig. 2)

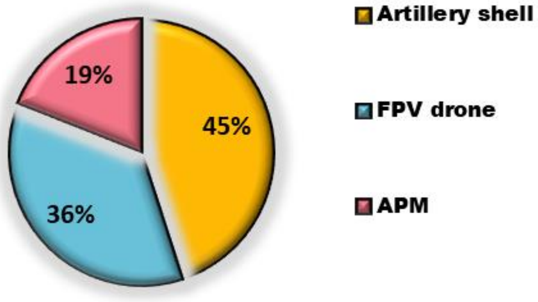

Fig. 2 The percentage of different types of weapons during the full-scale war in Ukraine, %.

A subsequent analysis of the structure of combat injuries among servicemen sustained as a result of the use of various types of weapons revealed that the most common types of injuries were lower limb amputations - 43.0% of cases. Amputations of the upper limb were observed in 18.0%, and combined amputations of the upper limb and both lower limbs - in 1.0% of servicemen. In addition, thoracic (10.0%), abdominal (18.0%) and thoraco-abdominal (10.0%) wounds are important types, indicating high kinetic energy causing combined injuries (Fig. 3).

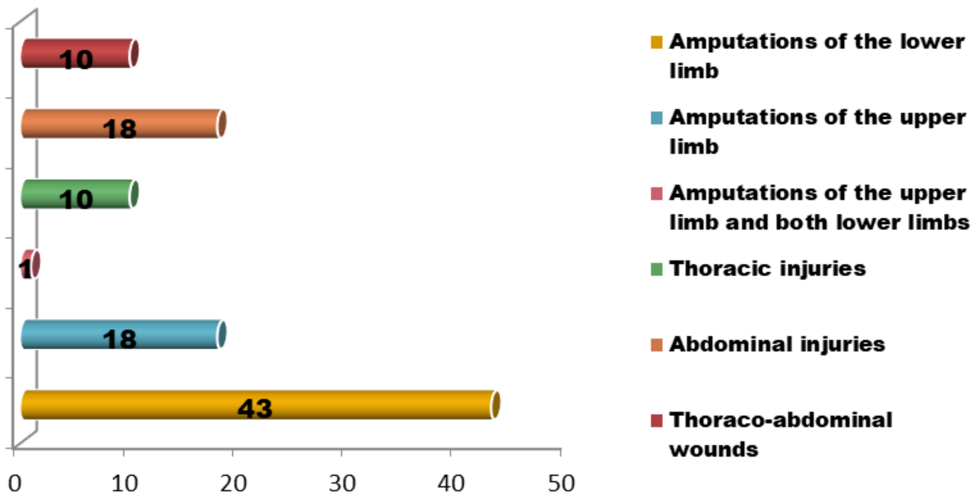

Fig. 3 Share of different types of injuries during the full-scale russo-Ukrainian war, %.

A microbiological analysis was conducted to identify the microbial spectrum of pathogens associated with combat wounds. According to the data obtained, the dominant pathogen of gunshot wounds was Acinetobacter spp. (36.0%), which is characterized by a high level of antibiotic resistance and pronounced adhesive properties, 21.0% - Klebsiella pneumoniae. This is a conditionally pathogenic bacterium that demonstrates resistance to β-lactam antibiotics and other groups of antimicrobial agents. Pseudomonas aeruginosa (15.0%) and Escherichia coli (9.0%) were also detected, characterized by the ability to biofilm formation and resistance to standard antibiotic therapy. Less common, but clinically significant, were Enterococcus spp. (6.0%), Enterobacter spp. (6.0%) and Proteus mirabilis (5.0%). The frequency of detection of gram-positive microorganisms (Staphylococcus spp., Achromobacter spp.) was low - 1.0% (Fig. 4).

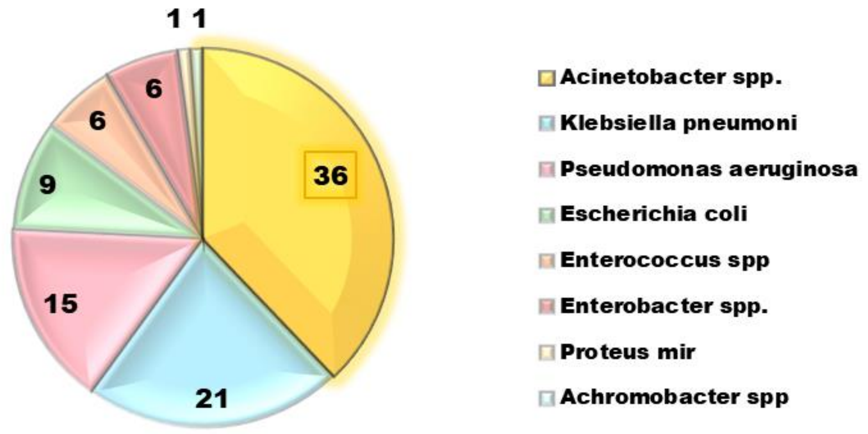

Fig. 4 Share of the microbial spectrum of pathogens in combat injuries of servicemen, %.

The results of the analysis of the rehabilitation period for injured servicemen with combat injuries demonstrated variability in the duration of the recovery period, depending on the severity and nature of combat injuries. In 41.0%, recovery lasted 1 month, indicating the effectiveness of early treatment and rehabilitation measures. In 48.0% of patients, the rehabilitation period was 1.5 months, which indicates the complexity of combat injuries and the need for comprehensive medical and rehabilitation support (physiotherapy, prosthetics, adaptation measures). Only 11.0%

of servicemen had a period of more than 2 months, due to severe combined injuries, development of infectious complications, reconstructive surgery, and the need for intensive treatment (Fig. 5).

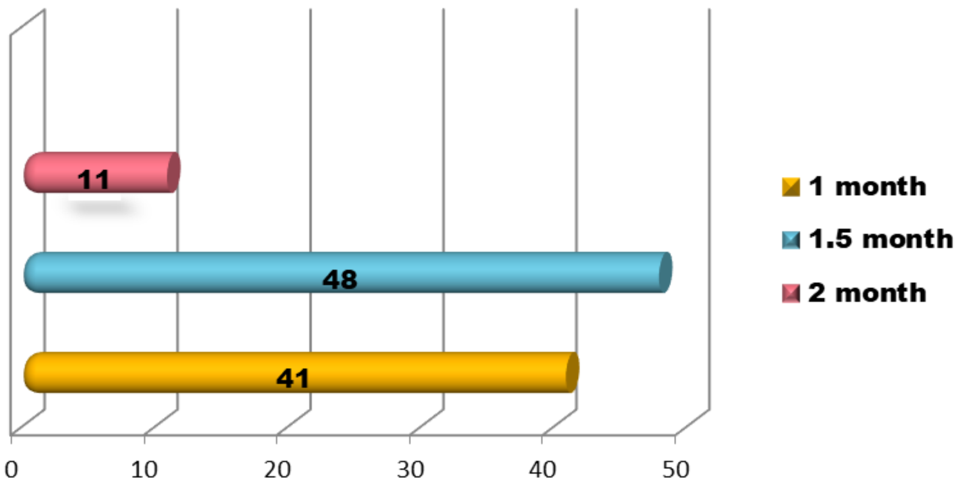

Fig.5 Distribution of Rehabilitation Periods for Injured Servicemen with Combat Injuries, %

Our findings emphasize the importance of an individualized and multidisciplinary approach to rehabilitation based on timely medical intervention, the use of modern rehabilitation programs, comprehensive physical rehabilitation, and the need for psychological support and social adaptation of servicemen and women after severe combat injuries. Successful rehabilitation requires not only restoration of physical functions but also a comprehensive approach to the psychological/mental state of patients, which will facilitate their full integration into society and improve their quality of life.

5.1.3. Preventive measures

Comprehensive prevention of combat injuries and their infectious complications is a complex and multilevel process that includes measures to prevent serious injuries, timely medical intervention and effective rehabilitation of military personnel.

We propose the following measures:

1. **Individual protection of military personnel:** The use of modern body armor, ballistic helmets or special protective clothing, safety goggles, which reduces the risk of fatal and serious injuries.

2. **Personnel training (tactical medicine):** training military personnel in tactical medicine skills (self- and mutual aid) in accordance with international standards of TCCC (Tactical Combat Casualty Care), providing individual first aid kits, organizing evacuation corridors with priority for seriously injured to medical facilities.

3. **Antibiotic prophylaxis and prevention of infectious complications:** use of antibiotics according to the microbial spectrum, use of broad-spectrum antibiotics at the pre-hospital stage with subsequent readjustment, antiseptic wound treatment to minimize the risk of infectious complications.

4. **Upgrade of the rehabilitation system:** introduction of rehabilitation programs with an emphasis on a multidisciplinary, integrated approach, provision of psychological support and social adaptation of servicemen, creation of state programs to support war veterans.

CONCLUSIONS

1. Our meta-analysis revealed that the full-scale war in Ukraine, due to the modernization of military weapons and the changing nature of combat injuries, is accompanied by a high incidence of IEDs, which are the main cause of combat injuries, of which combined injuries were most often observed in 47.8% of victims, multiple injuries in 36.1%, and isolated injuries in 16.1% of cases.

2. The analysis of the localization of combat injuries in Ukraine demonstrated that the dominant injuries were limb injuries, which ranged from 43.7 to 62.6% of the total number of injuries, including 36.9% of lower limbs and 25.7% of upper limbs; 84.3% had one limb amputated, 13.7% had two limbs amputated, and 2.0% had three limbs amputated.

3. Penetrating neck injuries were blast injuries in 73.0% of patients and gunshot wounds in 27.0%, and the survival rate to hospitalization remains critically low at about 7.0%.

4. The assessment of the microbiological profile of combat wounds found that the frequency of purulent-septic complications of gunshot wounds among military personnel was 50.0%-75.0% with a predominance of gram-negative flora with high antibiotic resistance, complicating treatment tactics and requiring careful modern selection of antibiotics.

5. According to the results of our study, the main cause of MBT is artillery shells, which account for 45.0% of the total number of injuries among servicemen, 36.0% - FPV drones, 19.0% - APMs. The most common types of injuries are lower limb amputations (43.0%), upper limb amputations were observed in 18.0%, combined amputations of the upper limb and both lower limbs in 1.0% of servicemen; the dominant pathogen of gunshot wounds was Acinetobacter spp. (36.0%), Klebsiella pneumoniae (21.0%), Pseudomonas aeruginosa (15.0%) and Escherichia coli (9.0%), Enterococcus spp. (6.0%), Enterobacter spp. (6.0%) and Proteus mirabilis (5.0%).

6. Rehabilitation of servicemen after combat injuries is a complex multicomponent process that includes medical, physical, psychological and social adaptation. In 41.0% of patients, recovery lasted 1 month, in 48.0% of patients the rehabilitation period was 1.5 months, and in 11.0% it lasted more than 2 months, depending on the severity of the injury.

7. It is suggested to implement an integrated, multidisciplinary approach to rehabilitation, which will significantly improve the psychofunctional, psychosomatic, psychological functions of the body, and contribute to improving the quality of life and social adaptation of military personnel.

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