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A differentiated approach to comprehensive surgical treatment of combined combat thermomechanical injuries

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In recent years, there has been a notable increase in the incidence of thermomechanical injuries, which frequently manifest as a combination of various types of damage. The majority of these injuries require long-term treatment and result in the development of decompensated (critical) conditions during the early stages, with a substantial death rate ranging from 75 % to 80 %.

Objective — to improve the results of surgery for combined combat thermomechanical injuries by developing and implementing a differentiated surgical approach that incorporates the assessment of injury severity within the context of medical support.

Materials and methods. A retrospective-prospective study was carried out to determine the effectiveness of medical care provided for wounded individuals with combined combat thermomechanical injuries sustained during combat operations between 2017 and 2023. The study included a cohort of 97 wounded individuals, who were subsequently divided into two separate clinical groups. The main group (n = 56) underwent treatment according to a differentiated surgical approach that included the assessment of the severity of the patient's condition using the admission trauma scale (AdTS) and the perfusion index (PI). The control group (n = 41) received treatment based on established protocols using conventional treatment approaches for combined combat thermomechanical injuries without considering prioritisation.

Results. A differentiated surgical strategy for managing combined combat thermomechanical injuries, which included an objective assessment of injury severity using the AdTS and the perfusion index (PI), allowed for a notable decrease in the occurrence of late purulent-septic complications as well as a significant reduction in the mortality rate in the main group to 21.4 %, compared to 38.8 % in the control group ($p = 0.038$). This was related to a decrease in the frequency of fatal outcomes among individuals with serious injuries: 21.2 % in the main group, 37.0 % in the control group ($p = 0.013$). Furthermore, surgical treatment improved anatomical and functional outcomes in the main group compared to the control group. Group 1 had a higher specific weight of favourable outcomes 52.0 ± 14.2 % and a lower specific weight of unsatisfactory outcomes (17.6), [8.7;28.7] %, compared to group 2 20.6 ± 13.4 % and 47.3 ± 14.7 %. The difference was statistically significant at $p = 0.001$.

Conclusions. The implementation of a differentiated surgical approach with an objective assessment of injury severity resulted in a reduction in mortality from 7.3 % to 1.8 %, specific weight of amputations from 34.2 % to 8.9 %, and contractures from 26.8 % to 10.5 % ($p < 0.05$). Early vacuum therapy in the surgical treatment of combined combat thermomechanical injuries reduced treatment time and allowed for early reconstructive and restorative operations, leading to better functional outcomes. The specific weight of favourable outcomes increased from 20.6 % to 52.0 %, while the relative number of unsatisfactory outcomes decreased from 47.3 % to 17.6 % ($p < 0.05$).

Keywords
combined combat thermomechanical injury, perfusion index, syndrome of mutual aggravation of injuries.

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In recent years, there has been a notable increase in the incidence of thermomechanical injuries. They frequently manifest as a combination of various types of damage, primarily affecting people of working age and resulting in severe conditions. The majority of these injuries require long-term treatment and result in the development of decompensated (critical) conditions during the early stages, with a substantial death rate ranging from 75 % to 80 % [3, 9, 7].

It should be noted that combined combat thermomechanical injury, which differs from civilian injury and is a separate category of mine-explosive injuries, includes a combination of burns received as a result of the action of a flame of incendiary material, the explosion of shells, missiles, and bombs as well as mechanical injuries caused by the impact of a shock wave or various projectiles (for example, bullets, shrapnel, or mine-explosive injuries). In the spectrum of all explosive injuries, combined combat thermomechanical trauma accounts for approximately 69—75 % [8, 14].

Modern explosives used in combat operations and causing combined combat thermomechanical injuries can be classified into high-order explosives and low-order explosives. High-order explosives have a significant supersonic pressure wave known as a blast wave or shock wave. Low-order explosives have a subsonic explosion and lack a high-order blast wave. In addition to the blast wave, the explosion can cause a shock wave. A shock wave is a stream of superheated air that can interact with people and objects and cause injury or damage [2].

Burn shock and traumatic shock are more severe in cases of extensive mechanical injuries and deep thermal burns compared to isolated mechanical injuries and thermal burns. These types of shock result from hemodiscirculatory disorders and occur due to blood and plasma loss. Burn wounds and carbon monoxide poisoning involving the respiratory tract aggravate the clinical manifestations of shock due to the development of all forms of hypoxia (circulatory, hypoxic, tissue, and mixed). Bleeding from damaged vessels and organs and loss of plasma and lymph in injured and burned tissues lead to hypovolemia, hemodynamic disorders, and impaired oxygen transport. More than 85 % of burn and traumatic shock patients have serious acid-base balance disorders of the blood and lymph, hemo- and lymphodynamics, metabolic processes, and functional abnormalities in the liver and kidneys. If no medical assistance is provided, the risk of death increases dramatically [16].

Some studies focus on the correlation between thermal injuries and the development of burn disease and a non-specific systemic inflammatory response syndrome (SIRS). Their findings indicate that a superficial burn of 15 % of the body surface is associated with the syndrome of mutual aggravation, which is characterised by more severe clinical signs of shock and a high incidence of purulent-septic complications in the post-shock period [1, 15].

In modern literature, there is no consensus on the appropriate indications, contraindications, and management strategies for burn shock and traumatic shock, as well as the treatment of their combined manifestation in the presence of the syndrome of mutual aggravation. This lack of agreement extends to several aspects of medical support, including modern resuscitation measures, differentiated surgical treatment, support during transportation, and subsequent restorative treatment of combined combat thermomechanical injuries. These factors have prompted further research under the current conditions of combat operations [4].

Objective — to improve the results of surgery for combined combat thermomechanical injuries by developing and implementing a differentiated surgical approach that incorporates the assessment of injury severity within the context of medical support.

Materials and methods

A retrospective-prospective study was carried out to determine the effectiveness of medical care provided for wounded individuals with combined combat thermomechanical injuries sustained during combat operations between 2017 and 2023. The study was conducted at the injury clinic of the National Military and Medical Clinical Centre «The Main Military Clinical Hospital» (Kyiv), the burn department of Kyiv City Clinical Hospital No. 2, and the orthopaedic and traumatology department of Kyiv City Clinical Hospital No. 8. A total of 376 case histories were analysed. The study included a cohort of 97 wounded individuals, who were subsequently divided into two separate clinical groups. The main group (n = 56) underwent treatment according to a differentiated surgical approach that included the assessment of the severity of the patient's condition using the AdTS, the perfusion index (PI), and modern methods of treatment. The control group (n = 41) received treatment based on established protocols using conventional treatment approaches for combined combat thermomechanical injuries without assessing injury severity or considering prioritisation.

After receiving first aid at level I care, the injured were transported to level II care. In the first hour after the injury, we admitted 11 (19.6 %) and 8 (19.5 %) individuals; in the second hour, 29 (51.8 %) and 23 (56.1 %) individuals; and between 2 and 24 hours, 16 (28.6 %) and 10 (24.4 %) individuals (Table 1).

Table 1. **Admission time for level I care**

Admission time	Group 1 (n = 56)	Group 2 (n = 41)
Up to 1 hour	11 (19,6 %)	8 (19,5 %)
From 1 to 2 hours	29 (51,8 %)	23 (56,1 %)
From 2 to 3 hours	7 (12,5 %)	5 (12,2 %)
From 3 to 6 hours	5 (8,9 %)	3 (7,3 %)
After 6 hours	1 (1,8 %)	0
Unknown	3 (5,4 %)	2 (4,9 %)

All of the wounded individuals had multiple and combined mine-explosive injuries. The most commonly diagnosed injuries in Group 1 and Group 2 were upper limb injuries, with 32 (57.1 %) and 24 (58.5 %) cases, respectively, and lower limb injuries, with 24 (42.9 %) and 17 (41.5 %) cases, respectively.

Based on the type of wound tract, 159 wounds were penetrating, and 58 wounds were perforating. No statistically significant difference was found among the comparison groups in terms of the trajectory of the wound tract ($p > 0.05$ for both groups). The comparison groups were comparable (Table 2).

With regard to the depth of burn wounds, the IIa degree group suffered the most injuries, with 25 (43.9 %) and 18 (43.9 %), respectively (Table 3).

The extent of anatomical damage, anatomical and functional severity of injury, general clinical indicators, biochemical findings, coagulograms, as well as respiratory and circulatory disorders, were assessed before, during, and after conservative and operative treatment within the context of medical support.

Table 2. **Distribution of the types of wound tract in comparison groups**

Type of wound tract	Group 1 (n = 56)	Group 2 (n = 41)	Significance of the difference
Penetrating	96 (72,7 %)	64 (74,4 %)	$\chi^2 = 0{,}076$ $p = 0{,}783$
Perforating	36 (27,3 %)	22 (25,6 %)	
Total	132	86	

Table 3. **The degree of burns in combined combat thermomechanical injuries in the study groups**

Degree of burn	Group 1 (n = 56)	Group 2 (n = 41)	Significance of the difference
IIa	25 (43,9 %)	18 (43,9 %)	$\chi^2 = 0{,}873$ $p = 0{,}647$
IIb	14 (24,6 %)	13 (31,7 %)	
III	16 (31,6 %)	10 (24,4 %)	

Correlation analysis revealed a reliable relationship between the anatomical and functional assessment of injury severity according to the PTS (Polytrauma-Schlussel) and the value of PI in the wounded individuals both on admission (Spearman correlation coefficient $r = -0.61$; $p = 0.01$) and in the first 1—3 days after injury ($r = -0.62$; $p < 0.001$). At the same time, the relationship between the score assessment of injury severity on the PTS scale and the AdTS was less pronounced ($r = +0.31$; $p = 0.095$).

The collected statistical information was analysed and processed using the Statistica 8.0 and Microsoft Excel 2021 programmes. The study focused on the assessment of the absolute (m) and frequency (p) characteristics of indicators for qualitative parameters as well as average values for quantitative data (arithmetic mean X) and their variability (mean square deviation σ). Pearson's Chi-square (χ^2) test was used to compare the group frequency of a specific parameter.

Results

In the study groups, surgical treatment of combined combat thermomechanical injuries was approached differently. In the main group, it included an objective assessment of injury severity using the AdTS and the perfusion index (PI), life-saving measures aimed at reducing the volume, duration, and traumatic impact of the first operation at level II care, and the final restoration of damaged organs and structures after stabilising vital bodily functions during the second operation at levels III and IV care.

On admission of a wounded person with a severe and extremely severe injury to level II care, first of all, anti-shock measures were performed according to damage control tactics, aimed at combating three main life-threatening conditions: coagulopathy, hypothermia, and acidosis. The concept of damage control, in addition to the specified triad, includes the «two hit theory» («first hit» — systemic inflammatory response, «second hit» — blood loss, shock, reaction to surgical intervention).

Individuals with non-severe combined combat thermomechanical injuries received comprehensive surgical care in the dressing room or operating room, depending on their needs. In situations of severe and extremely severe injuries, the scope of surgical care was reduced in accordance with DCS. The medical procedures started in the anti-shock ward, and after stabilising the patient's condition, they were transferred to the operating room. In situations of

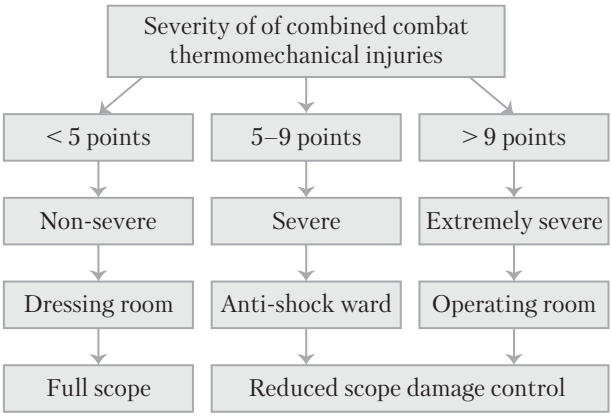

Figure 1. **A differentiated approach to the surgical treatment of combined combat thermomechanical injuries**

extremely severe injuries, a full scope of surgical treatment was provided in the operating room (Fig. 1).

Based on the assessment of injury severity using the AdTS and the value of the perfusion index, the place, scope, and sequence of diagnostic procedures were determined to identify the main clinical and laboratory indicators of homeostasis, integral indicators, single heart output, the coefficient of integral vascular tonicity, the rate of respiratory tension, the rate of tone stabilisation of blood vessels, indicators of the severity of respiratory and circulatory disorders, and indicators of SpO_2 and heart rate.

The full scope of surgical intervention for combined combat thermomechanical injuries included the following procedures: primary surgical treatment of gunshot wounds to stop external bleeding; preventive and curative fasciotomy of the muscle and fascial compartments of the damaged limb segment; limb amputation when necessary; stabilisation of bone fragments using a rod apparatus for external fixation; necrotomy; early necrectomy of the burned tissue; and, in cases of burns involving more than 40 % of the body area, staged necrectomy. The reduced scope of surgical intervention included the following procedures: cessation of external bleeding, therapeutic fasciotomy, necrotomy for circular burns of the trunk and limbs, and stabilisation of bone fragments using a rod apparatus for external fixation.

At the next level of care, further comprehensive management of combined combat thermomechanical injuries included vacuum-assisted closure treatment (VAC-technique) for burn wounds, during which negative pressure was applied to a white foam dressing when available (Fig. 2), which made it possible to maintain constant temperature in the wound, reduce bacterial insemination, decrease edema, reduce intercellular pressure, stimulate the formation of granulation tissue, and reduce the wound surface area.

Irrigation-oxygen vacuum therapy was also used to reduce the risk of the progression of anaerobic infection. It included the application of an antiseptic solution along with oxygen. An oxygen concentrator was administered to treat the wound with negative pressure and constant insufflation with oxygen without the threat of depressurization of the wound due to the adjustment of the dosed supply of oxygen to the wound (Fig. 3).

The implementation of a differentiated surgical approach with an objective assessment of injury severity resulted in a reduction in mortality from 7.3 % to 1.8 %, specific weight of amputations from 34.2 % to 8.9 %, and contractures from 26.8 % to 10.5 % ($p < 0.05$). Furthermore, it reduced the treatment period and allowed for the conversion of the osteosynthesis method at level IV care, which improved the functional outcomes of treatment: the specific weight of favourable outcomes increased from 28.6 % to 51.0 %, and the relative number of unsatisfactory outcomes decreased from 39.3 % to 17.6 % ($p < 0.05$) (Table 4).

A notable decrease in the occurrence of late purulent-septic complications led to a significant reduction in the mortality rate in the main group to 21.4 %

Figure 2. **Wounded D.: treatment of burn wounds with a white foam dressing**

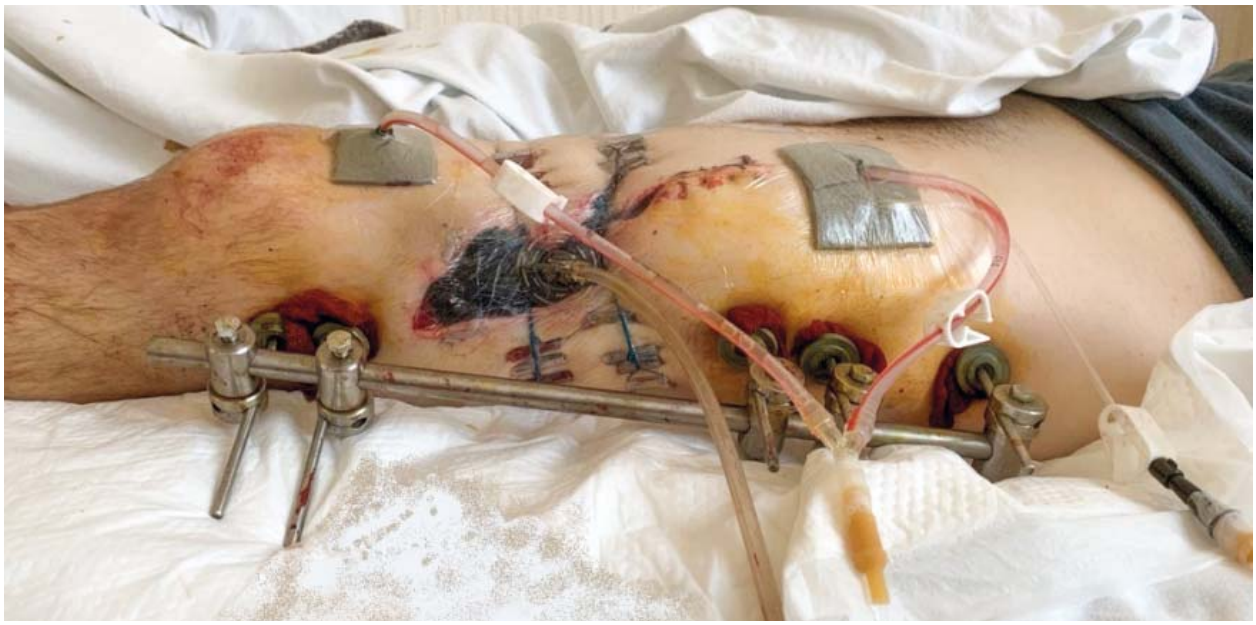

Figure 3. **Wounded K.: the condition after surgical treatment and installation of an irrigation-oxygen vacuum system**

compared to 38.8 % in the control group (p = 0.038). This was related to a decrease in the frequency of fatal outcomes among individuals with serious injuries: 21.2 % in the main group, 37.0 % in the control group (p = 0.013). The mortality rate directly depended on the development of burn shock and traumatic shock, which were more severe than in cases of isolated mechanical injuries and thermal burns. Endotoxemia occurred due to the absorption of decomposition products from injured and ischemic tissues, leading to the formation of toxic substances inside the body. It contributed to the syndrome of mutual aggravation, which had more severe clinical signs of shock and a significant number of purulent-septic complications in the post-shock period.

Furthermore, surgical treatment improved anatomical and functional outcomes in the main group compared to the control group. Group 1 had a higher specific weight of favourable outcomes (52.0 %) and a lower specific weight of unsatisfactory outcomes (17.6 %), compared to group 2 (20.6 %) and (47.3 %) (Table 5).

Table 4. **Analysis of the specific weight of amputated limbs at the level of the thigh in comparison groups**

Indicator	Group 1 (n = 56)	Group 2 (n = 41)
Amputation	6 (8,9 %)	14 (34,2 %)
Limbs saved	50 (91,1 %)	27 (65,8 %)

Table 5. **Analysis of the quality of treatment of the wounded according to the scale of anatomical and functional outcomes of Mathis–Luboshits–Schwartzberg**

Functional outcomes	Group 1 (n = 56)	Group 2 (n = 41)
Good	27 (52,0 %)	8 (20,6 %)
Satisfactory	20 (30,4 %)	14 (32,1 %)
Unsatisfactory	9 (17,6 %)	19 (47,3 %)

Clinical case

Wounded D., 34 years old. Mine-explosive injury (10.06.23). Combined injury. Gunshot shrapnel wound of the left lower limb with a gunshot multifragmentary fracture of the femur, tibia, and foot on the left. Thermal burns of the left lower limb IIa and IIb degree, amounting to 11% and 5% body area respectively.

The condition of the wounded was assessed as severe, according to the AdTS of 8 points and the PI of 3.7. In the operating room, primary surgical treatment of gunshot wounds of the left lower limb with fasciotomy, installation of a rod apparatus for external fixation on the left lower limb (segment: thigh, lower leg, foot), and toileting of the burn surface were performed (Fig. 4). After stabilisation of the condition, evacuation to the next level of care.

At level III care, the surgical intervention was carried out as a result of the non-viability of the limb. The procedure included the amputation of the left lower limb at the level of the middle third

Figure 4. **Wounded D.: during surgical procedure**

of the thigh, followed by the formation of a stump. The postoperative period was uneventful. After the healing of the stump, the fragments of the upper third of the left femur continued to be displaced, making it impossible to begin limb prosthetics with further rehabilitation. For this purpose, the intramedullary osteosynthesis of the left femur was conducted using the PFNA (Fig. 5).

The postoperative period was without complications. Early rehabilitation was started, and sutures were removed on the 10th day (Fig. 6). The total period of treatment at all levels of care was 47 days.

Discussion

The management of combined combat thermomechanical injuries at all levels of care is a challenging issue that requires complex and well-considered decisions to be made over a period of time [5, 13]. The proposed differentiated approach makes it possible to reduce the time for assessing the severity of combined combat thermomechanical injuries using the AdTS and the perfusion index (PI), whose prognostic value is not inferior even to the widespread PTS [10]. However, their application is technically simpler and does not require significant costs, in contrast to other prognostic methods of assessing the severity of combined combat thermomechanical injuries [6].

The application of the AdTS and the PI increases the effectiveness of treatment and minimises the risk of complications resulting from both full-scope and reduced-scope surgical interventions. This approach mitigates the impact of misclassifying combined combat thermomechanical injuries as either traumatic injuries or burns [11] and takes into account the syndrome of mutual aggravation. This syndrome involves two or more anatomical and functional systems of the body and is characterised by the simultaneous action of several diverse pathophysiological processes on the body. The dominance of one pathological process over another depends on the mechanism of injury. It is

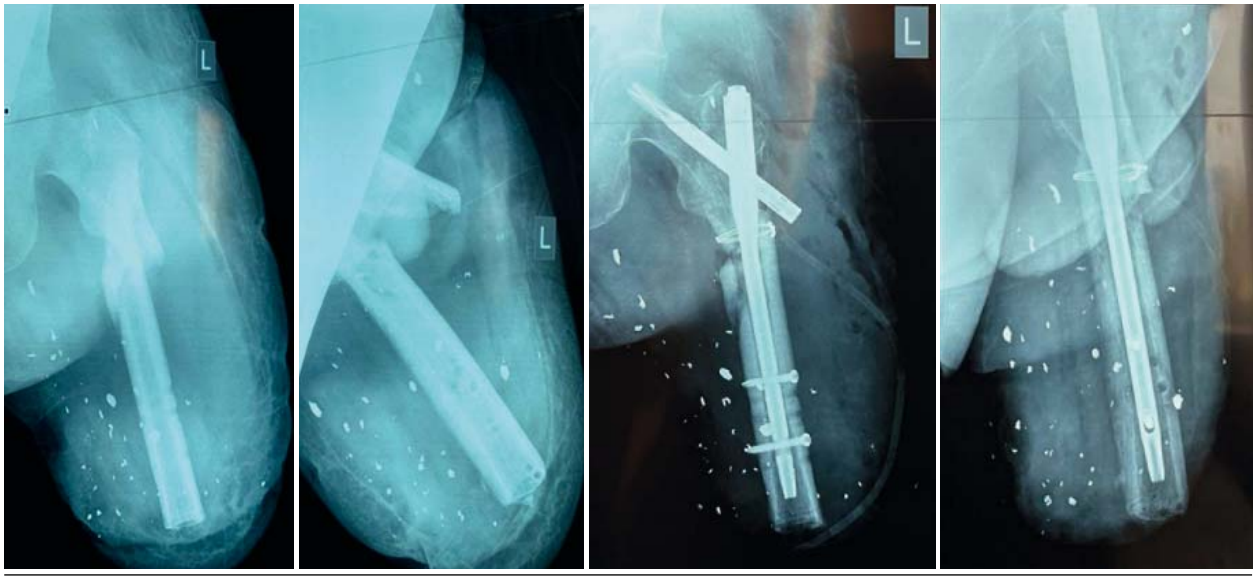

Figure 5. **Wounded D.: intramedullary osteosynthesis of the left femur using the PFNA**

Figure 6. **Wounded D.: early and late postoperative period**

characterised by a significant and rapid impairment of the autoregulation of the inflammatory process, resulting in a competitive interaction between pro-inflammatory and anti-inflammatory cytokines, leading to irreversible changes such as multiple organ failure, sepsis, and the death of the wounded.

The development and implementation of modern approaches to comprehensive surgical treatment of combined combat thermomechanical injuries as well as their impact on various aspects of traumas and burns, including the wound process, remain relevant. In contrast to conventional methods of surgical treatment, the application of the VAC technique (irrigation-oxygen vacuum therapy) in the management of burn wounds allows us to reduce the risk of complications and the treatment period, effectively control the wound process, and maximally preserve the functionality and aesthetics of burn skin defects with subsequent early plastic surgery, rehabilitation, and restoration of motor activity, which contributes to a higher quality of life [12].

Conclusions

The implementation of a differentiated surgical approach with an objective assessment of injury severity resulted in a reduction in mortality from 7.3 % to 1.8 %, specific weight of amputations from 34.2 % to 8.9 %, and contractures from 26.8 % to 10.5 % ($p < 0.05$).

Early vacuum therapy in the surgical treatment of combined combat thermomechanical injuries reduced treatment time and allowed for early reconstructive and restorative operations, leading to better functional outcomes. The specific weight of favourable outcomes increased from 20.6 % to 52.0 %, while the relative number of unsatisfactory outcomes decreased from 47.3 % to 17.6 % ($p < 0.05$).

Declaration of interests

The authors declare no potential conflicts of interest.

Funding. No grants or funding were used in this study.

Ethics approval and written informed consents statements

The study was conducted in accordance with the Helsinki Declaration of Ethics. The study protocol was approved by the ethics committee of the Ukrainian Military Medical Academy.

Authors contributions

S. O. Korol: idea, design, formalisation, conclusions; I. P. Palii: materials and methods, design, data processing, statistics.

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Диференційована хірургічна тактика в комплексному лікуванні поранених із бойовою комбінованою термомеханічною травмою

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Термомеханічні ушкодження часто є комбінованим видом уражень. Більшість цих ушкоджень потребують тривалого лікування та призводять до розвитку декомпенсованих (критичних) станів у ранні терміни після поранення з високою летальністю (75—80 %).

Мета — поліпшити результати хірургічного лікування поранених із бойовою комбінованою термомеханічною травмою (БКТМТ) шляхом розробки та впровадження диференційованої хірургічної тактики з урахуванням оцінки тяжкості на рівнях медичного забезпечення.

Матеріали та методи. Для оцінки ефективності надання медичної допомоги пораненим із БКТМТ під час бойових дій за період із 2017 до 2023 р. проведено ретроспективно-перспективне дослідження. Пацієнтів (n = 97) розподілили на дві групи. В основній групі (n = 56) лікування проводили за диференційованою хірургічною тактикою з урахуванням тяжкості стану пораненого за шкалою оцінки тяжкості травми AdTS та величиною перфузійного індексу (ПІ). Контрольну групу (n = 41) лікували загальноприйнятими методами без урахування пріоритетів.

Результати. Диференційована хірургічна тактика надання хірургічної допомоги пораненим із БКТМТ з об'єктивною оцінкою тяжкості травми за шкалою AdTS та ПІ дала змогу зменшити кількість пізніх гнійно-септичних ускладнень, що сприяло зменшенню кількості летальних наслідків в основній групі до 21,4 %, тоді як у контрольній групі таких випадків було 38,8 % (p = 0,038). Це зумовлено зменшенням частоти летальних наслідків у поранених із тяжкою травмою: в основній групі — 21,2 %, у контрольній групі — 37,0 % (p < 0,05). Анатомо-функціональні результати лікування в основній групі були кращими, ніж у контрольній групі. В основній групі зафіксовано більшу частоту добрих результатів — 52,0 і 20,6 % відповідно і меншу частоту незадовільних — 17,6 та 47,3 % (p < 0,05).

Висновки. Упровадження диференційованої хірургічної тактики з урахуванням тяжкості травми дало змогу зменшити рівень летальності з 7,3 до 1,8 %, частку ампутацій — з 34,2 до 8,9 %, кількість контрактур — з 26,8 до 10,5 % (p < 0,05). Застосування ранньої вакуумної терапії при хірургічному лікуванні у пацієнтів із БКТМТ дало змогу скоротити тривалість лікування та провести в ранні терміни реконструктивно-відновні операції, що поліпшило функціональні результати лікування: частка добрих результатів збільшилася з 20,6 до 52,0 %, а незадовільних — зменшилася з 47,3 до 17,6 % (p < 0,05).

Ключові слова: бойова комбінована термомеханічна травма, перфузійний індекс, синдром взаємного обтяження.

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