UDC 617.5-001.45-089:355+ [616.717.4/.6-001.5+616.718.4/.6-001.5]-089:355
DOI http://doi.org/10.30978/GS-2024-4-8

ISSN 2786-5584 print
ISSN 2786-5592 online

Peculiarities of a differentiated approach to surgical treatment of patients with combined combat thermomechanical injuries and long-bone gunshot fractures by the levels of patient care

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Objective — to improve treatment outcomes for wounded individuals with long-bone fractures and combined combat thermomechanical injuries (CCTMI) by developing and implementing a differentiated approach to surgical treatment at different levels of patient care.

Materials and methods. The surgical outcomes of 178 wounded individuals with long-bone fractures and CCTMI were investigated. The study employed general clinical, surgical, laboratory, biochemical, morphological, and statistical methods. The wounded individuals were divided into two clinical comparison groups: the main group and the control group. The main group included 91 wounded individuals with long-bone gunshot fractures who underwent surgical treatment according to a differentiated surgical approach that involved assessing the severity of CCTMI. The control group included 87 wounded individuals with long-bone gunshot fractures and CCTMI who received standard surgical treatment for burn and gunshot wounds. The comparative analysis was carried out based on age, the specific gravity of long-bone gunshot fractures, body surface area of the burn, type of wound tract, number of wounds, type of injury, time of admission, the effectiveness of organizational and medical interventions ($p > 0.05$).

Results. The analysis of treatment interventions revealed that the incidence of fasciotomies in the main group was 27.47 % compared to only 9.20 % in the control group. Additionally, the application of vacuum therapy reached 40.91 % versus 23.17 % in the control group ($p < 0.05$). In CCTMI with significant bone defects, the main group used more modern fragment-fixing procedures, including the Ilizarov apparatus and the two-stage Masquelet technique (84.09 % vs. 50.00 %, $p < 0.01$). The use of the admission trauma scale (AdTS-CCTMI) and the perfusion index in all cases of the main group facilitated the timely assessment of the patient's condition, improving treatment quality and preventing complications. In terms of early complications, the main group had considerably lower rates of anemia (62.64 % vs. 78.16 %, $p < 0.05$), resulting in fewer metabolic changes in the myocardium (23.08 % vs. 36.78 %) and acute renal failure (9.89 % vs. 14.94 %). The control group experienced nearly twice as many thromboembolic problems (12.64 % vs. 7.69 %, $p < 0.05$), highlighting the need for improved preventive measures. Among the late complications, postoperative wound suppuration and osteomyelitis remained significant challenges. However, these complications were less common in patients in the main group (9.89 % and 6.59 %, respectively) than in the control group (21.84 % and 16.09 %). 4.40 % of patients in the main group underwent limb re-amputations for gangrene or osteomyelitis compared to 10.34 % in the control group ($p < 0.05$).

Conclusions. The functional treatment outcomes, as measured by the Mattis-Lyuboshyts-Schwarzberg scale, demonstrated an increase in the proportion of good results from 39.08 ± 5.23 % to 56.98 ± 2.85 %, with a decrease in the relative number of unsatisfactory results from 18.39 ± 4.15 % to 6.24 ± 0.31 %, at $p < 0.05$. A differentiated surgical strategy with an objective assessment of injury severity at different levels of patient care resulted in a decrease in mortality from 10.34 % in the control group to 5.49 % in the main group, reflecting a reduction of 4.85 %.

Keywords
combined combat thermomechanical injury, gunshot wound, polytrauma, syndrome of mutual aggravation of injuries, traumatic shock, burns.

ARTICLE • Received 2024-10-25 • Received in revised form 2024-12-11

Combined injuries, which occur during simultaneous or sequential exposure to several damaging factors, are the primary issue associated with weapon use [3, 14]. In the context of increasing armed conflicts in many countries, an urgent problem is the search for effective surgical strategies at different levels of patient care, which would contribute to the effective treatment and rapid rehabilitation of the wounded with combined combat thermomechanical injuries (CCTMI) in a short time [12].

Combined combat thermomechanical injuries with varying degrees of burns lead to disability, which has psychological, social, and economic repercussions for the wounded individuals in addition to physiological ones. One of the stages of CCTMI management is the treatment of dermal burns using biological and synthetic wound dressings [8]. The traditional methods for treating thermomechanical injuries locally and surgically and preventing complications do not adequately account for modern capabilities [10]. Therefore, new pathogenetically based strategies in the surgical management of CCTMI remain a significant medical and social challenge.

CCTMI may cause damage leading to the development and generalization of the infectious process. Such complications are always associated with thermomechanical skin damage, which is a three-dimensional mass of damaged tissues. The damaged area has three distinct zones: hyperemia, coagulation, and paranecrosis. Thermal and mechanical factors cause the microcirculatory bed and its endothelial barrier to become permeable to plasma and intravascular proteins. In this zone, blood circulation stops, microthrombi form and necrosis develops, the severity of which depends on the depth of the injury [7, 12]. Considering the characteristics of thermomechanical injury, various treatment strategies will reduce the risk of complications, particularly the syndrome of mutual aggravation, wherein the pathological process, caused by many factors, exhibits a more severe course than that of monofactorial damages.

In CCTMI, pathophysiological changes that cause homeostasis disorders play a key role [1, 5]. It is these mechanisms, along with stress factors, that lead to the development of infectious complications in wounded individuals [6].

Another problem in CCTMI management is ensuring effective surgical treatment at different levels of patient care since the earlier differentiated surgical strategy is employed, the fewer complications develop [15]. A differentiated approach to the surgical treatment of CCTMI at levels II, III, and IV care will significantly reduce the rate of complications and mortality. The search for new surgical techniques for the treatment of wounded individuals with CCTMI is relevant.

Objective — to improve treatment outcomes for wounded individuals with long-bone fractures and combined combat thermomechanical injuries by developing and implementing a differentiated approach to surgical treatment at different levels of patient care.

Materials and methods

The effectiveness of medical care was assessed for 178 people aged 18 to 60 years with CCTMI sustained during combat operations between 2017 and 2023. They were admitted to the burn department of Kyiv City Clinical Hospital No. 2, the injury clinic of the National Military and Medical Clinical Centre «The Main Military Clinical Hospital» (Kyiv), and the orthopedic and traumatology department of Kyiv City Clinical Hospital No. 8.

The study used general clinical (monitoring of the patient's overall state), surgical, laboratory (peripheral blood tests), biochemical (analysis of biochemical markers), morphological, and immunological (determination of cytokine and growth factor levels) methods.

Patients were divided into two clinical groups according to the level of patient care and surgical treatment: the main group and the control group.

The main group included 91 (51.12 %) wounded individuals with long-bone gunshot fractures who underwent treatment according to a differentiated surgical approach that involved assessing the severity of CCTMI. The admission trauma scale (AdTS-CCTMI) was used to assess trauma severity. We considered the course of burn disease and the characteristics of mechanical injury that were adequately managed using modern surgical techniques and additional treatments for burn and gunshot wounds, as well as means of stabilizing long-bone gunshot fractures (Fig. 1).

In case of minor trauma, patients with gunshot wounds and burns received comprehensive surgical care in the dressing room or operating room, depending on the need. This care included wound treatment, necrectomy of burn wounds, fasciotomy, infusion therapy, and modern medical technologies. At level II care, in case of severe and extremely severe trauma, the scope of surgical intervention was reduced to minimal and was consistent with damage control surgery protocols. It included control of external bleeding, anti-shock measures, fasciotomy, longitudinal incisions for circular burns of the limbs and body, and primary stabilization of long-bone fractures using a rod apparatus for external fixation.

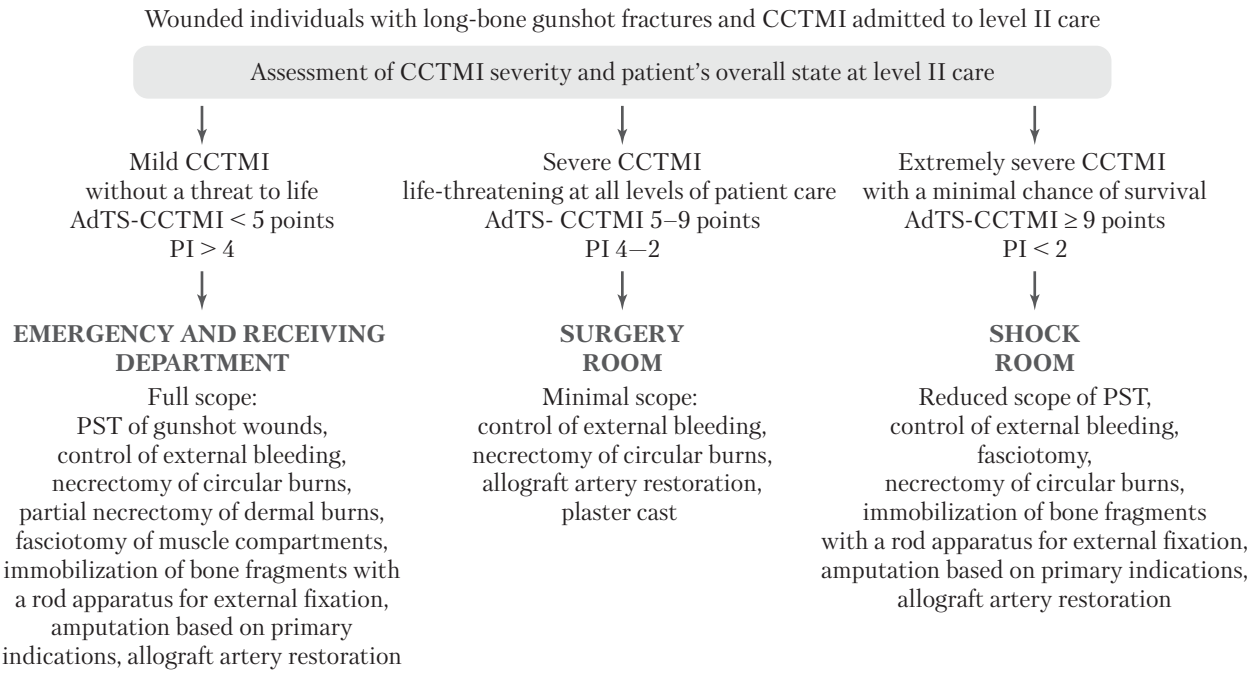

Figure 1. **Surgical strategy depending on the severity of combat surgical trauma**

The control group included 87 (48.88 %) wounded patients who received standard surgical treatment for burn and gunshot wounds without taking into account the severity of the condition according to AdTS-CCTMI and the course of burn disease.

An analysis of the causal factors contributing to CCTMI revealed that in the main group, 65 (71.4 %) wounded patients sustained thermomechanical injuries due to detonations from high-explosive mines, while 26 (28.6 %) incurred injuries from artillery shells impacting military equipment. In the control group, 61 (70.7 %) patients sustained CCTMI due to detonations from high-explosive mines, while in 26 (29.3 %) cases, the injuries resulted from artillery shells impacting military equipment.

Considering the characteristics of long-bone gunshot fractures and CCTMI, we observed 51 (56.04 %) patients with mild trauma (1—4 points) and 28 (30.77 %) patients with severe trauma (5—9 points) in the main group. The main group had the fewest patients with extremely severe trauma (> 9 points), with just 12 (13.19 %). Penetrating wounds prevailed (Table 1). The type of wound tract did not differ statistically significantly across the groups ($p > 0.05$).

In the main group, 50 (54.95 %) individuals had one gunshot wound, 25 (27.47 %) had two wounds, 10 (10.99 %) had three wounds, 5 (5.49 %) had four wounds, and only one (1.10 %) had five or more wounds. In the control group, 40 (45.98 %) individuals had one wound, 30 (34.48 %) had two wounds, 12 (13.79 %) had three wounds, 3 (3.45 %) had four wounds, and 2 (2.30 %) had five or more wounds.

The IIa-degree burns were most often diagnosed in the main group, accounting for 35 (38.46 %) of all wounded patients (Table 2). In the control group (n = 87), the number of wounded was slightly lower, with 30 (34.48 %) individuals. First-degree burns were observed in 20 (21.98 %) of the wounded in

Table 1. **Distribution of the wounded by comparison groups depending on the type of wound tract**

Type of wound tract	Main group (n = 91)	Control group (n = 87)
Penetrating	40 (44.0 %)	35 (40.2 %)
Perforating	51 (56.0 %)	52 (59.8 %)

Table 2. **Distribution of the wounded by burn depth**

Degree of burn	Main group (n = 91)	Control group (n = 87)
I	20 (22.0 %)	18 (20.7 %)
IIa	35 (38.5 %)	30 (34.5 %)
IIb	25 (27.5 %)	27 (31.0 %)
III	11 (12.1 %)	12 (13.8 %)

Table 3. **Distribution of the wounded by body surface area of the burn**

Affected area	Main group (n = 91)	Control group (n = 87)
< 10 %	40 (43.96 %)	35 (40.23 %)
10—39 %	35 (38.46 %)	40 (45.98 %)
≥ 40 %	16 (17.58 %)	12 (13.79 %)

the main group, somewhat more than in the control group, where 18 (20.69 %) were affected. The lowest proportion comprised extremely severe third-degree burns with extensive damage to the skin and underlying tissues. In the main group, such occurrences were recorded in 11 (12.09 %) individuals compared to 12 (13.79 %) in the control group.

An analysis of the wounded by body surface area of the burn (Table 3) revealed that the majority had burns covering < 10 % of the body: in the main group, 40 (43.96 %) individuals, and in the control group, 35 (40.23 %) individuals.

A differentiated approach was employed for the surgical treatment of the wounded in the main group, based on the assessment of injury severity using the AdTS–CCTMI scale.

In the primary surgical treatment (PST) of gunshot wounds and burn injuries, the wound was dissected, hemostasis was achieved, burn eschar and necrotic tissue were excised, and all branches of the wound tract and tissue «pockets» were drained. As required, open fasciotomy of all fascial sheaths was performed. Plaster cast immobilization was carried out, and a temporary rod apparatus for external fixation was used if necessary.

At level II care, amputations were conducted solely based on primary indications. Metal fragments located superficially in the body were removed using a magnet.

In the main group, the goal of the surgical treatment strategy was early necrectomy of burn and gunshot wounds to reduce further endointoxication of the body and minimize infectious complications with the fastest possible evacuation to level III care.

In the control group, patients received surgical care according to standard protocols without considering injury severity. Gunshot wounds and burns were treated sparingly. PST was conducted in a limited manner without excising tissues of questionable viability. Minimally invasive fasciotomy was carried out either prophylactically or decompressively. A rod apparatus for external fixation was usually installed permanently without further re-installation and conversion. No amputations were performed. All metal fragments were removed with a magnet. If necessary, ultrasound diagnostic devices and an electron-optical converter were used (Table 4).

The groups were comparable in age, frequency of long-bone gunshot fractures, body surface area of the burn, type of wound tract, number of wounds, type of injury, and time of admission to highly specialized treatment facilities of the Ministry of Defence and the Ministry of Health of Ukraine (Table 5).

The anatomical and functional treatment outcomes were evaluated using the Mattis-Lyuboshyts-Schwarzberg comprehensive scale (1980—1985), modified by Shevtsov (1995). The scale includes the following indicators: the presence of pain, the range of motion in the hip and knee joints, thigh shortening and deformation, radiological signs of fusion of the femur, muscle atrophy, vascular and neurological disorders, the presence of purulent complications and restoration of working capacity. A total index divided by 10 indicated a good anatomical and functional treatment result of

Table 4. **Treatment and organizational plan for selecting a surgical strategy at level II care**

Type of the procedure	Main group (n = 91)	Control group (n = 87)
PST of the wounds	Radical with removal of non-viable tissues and bone fragments	Sparing
Fasciotomy	Open	Minimally invasive
Installation of a rod apparatus for external fixation	With further correction	Without correction until conversion
Early necrectomy of dermal burns	Was performed	Was not performed
Primary amputations at level II care	According to MESS	Standard
Necrotomy of circular burns	Was performed	Was performed
Dressing of burn wounds	Hydrogel	Standard

Table 5. **Distribution of the wounded by the time of admission to the specialized department**

Timing of admission of the wounded to level IV care	Main group (n = 91)	Control group (n = 87)*
Up to 7 days from the moment of injury	70 (76.92 %)	65 (74.71 %)
After 7 days from the moment of injury	21 (23.08 %)	22 (25.29 %)

* $\chi^2 = 0{,}128$; $p_\alpha = 0{,}05$.

3.5—4.0 points, a satisfactory result of 2.5—3.5 points, and an unsatisfactory result of < 2.5 points.

The statistical processing and analysis of the obtained data were conducted using Statistica 8.0 and Microsoft Excel 2013.

We estimated the absolute (m) and frequency (p) values and calculated the arithmetic mean (M), standard deviation (σ), mean error, and confidence interval for the analyzed indicators. In cases where one of the alternatives was close to 0, the error was calculated using the Van der Waerden correction. At p > 75 % or p < 25 %, the sampling fraction had a substantial error, and the general fraction's confidence interval exceeded the permitted limitations ($p_L < 0$ % or $p_U > 100$ %). In such cases, the Fisher method was used to determine the confidence interval using the additional parameter ϕ. The general fraction's confidence interval was represented as a segment (p_L; p_U). Quantitative indicators were entered into the database unchanged.

The Pearson χ^2 criterion was used to assess the impact of each element on the overall feature under consideration. The Student t-criterion was used to conduct a more in-depth investigation of the factor's impact on individual gradations. The factor's impact on the feature was evaluated using the statistical significance threshold (p_α). The influence is statistically significant at $p_\alpha < 0.05$.

Results and discussion

A differentiated approach to surgical treatment of the wounded with CCTMI comprised an objective assessment of injury severity using the AdTS-CCTMI scale and the perfusion index with subsequent life-saving measures. This facilitated a reduction in the volume, duration, and traumatic nature of the first operation at level II care, allowing for the eventual restoration of organs and bodily structures if vital functions stabilized during the second operation at level III or IV care.

At level I care, CCTMI management included temporary control of external bleeding with the application of a tourniquet and an aseptic dressing to the burn wound (Fig. 2). Tight wound tamponade and infusion therapy of 800—1200 ml were performed. For this purpose, a 0.9 % sodium chloride solution, Ringer's lactate solution administered at 500 ml/h, and rheosorbilact were used. Transport immobilization was carried out using Kramer or SAM splints. Painkillers were delivered intramuscularly or intravenously. Antibiotic therapy and subcutaneous administration of toxoid in a dose of 1.0 ml were administered.

The basis of surgical treatment of the wounded with CCTMI at level II care was PST of gunshot and burn wounds to avoid or reduce the frequency of possible complications. Depending on the general condition of the wounded, blood parameters, SpO_2,

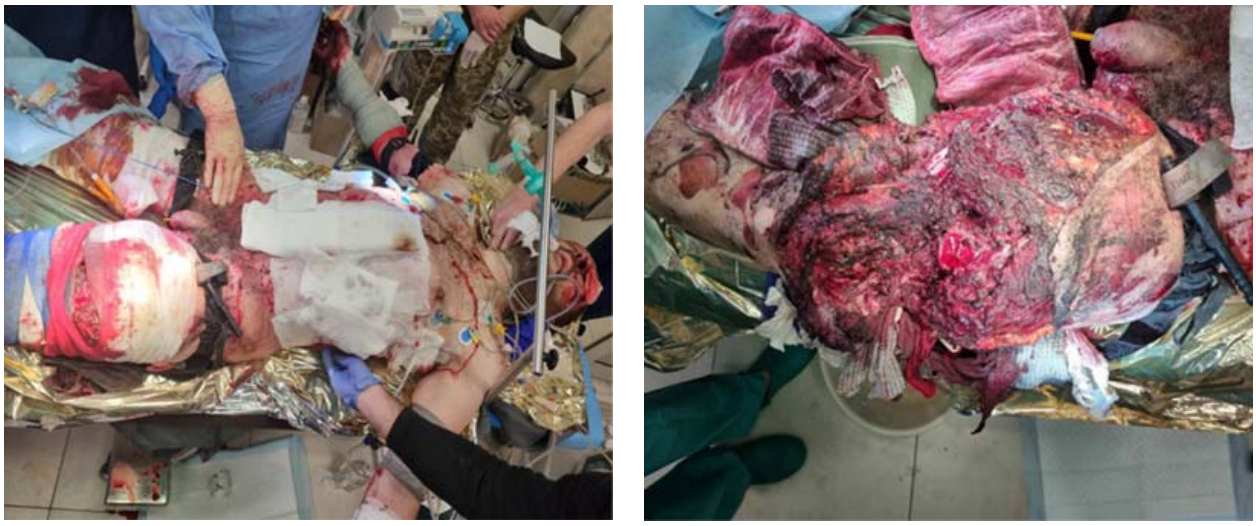

Figure 2. **Providing medical care to a patient with CCTMI**

PI, and surgical treatment were carried out in a full or reduced volume. In the latter case, a wide wound and decompression skin dissection and fasciotomy of the entire length of the sheaths in circular limb burns were performed (Fig. 3). The wound tract was revised. Blood clots, foreign bodies, and small bone fragments that were not connected to soft tissues were removed.

Autodermoplasty was performed on the hands, feet, and groin using a non-perforated autodermal graft. Individual atraumatic bandages for the fingers were necessarily used, adhering to the following requirements:

1. Non-adhesiveness of the first layer (paraffin mesh).
2. Maximum absorption of the layer.
3. Elastic fixation bandage.
4. In the event of an infectious process in the wound, an additional layer of antiseptic dressing was applied.

To prevent scarring, a perforated autodermal graft was used in a ratio of 1 : 1 or 1 : 1.5 relative to the skin, and to prevent mortality in cases of extensive deep burns, the ratio to the skin was 1 : 3 or 1 : 6.

If the burns were superficial epidermal, they were cleaned and coated with an atraumatic covering. For mild burns, a multilayer bandage was used to compress the autologous skin, while vacuum therapy was employed for severe burns. Local antibiotics were avoided due to their low effectiveness.

Long-bone fractures in the affected segment were stabilized using a rod apparatus for external fixation. Three Schantz screws were inserted proximally, followed by at least three screws distally relative to the long-bone fracture site beyond the wound surface (Fig. 4). If Schantz screws could not be inserted outside the wound, they were passed through it or, as an exception, the limb was immobilized with a plaster splint. The wounds were left open for drainage and dressed with a layer of fine-mesh gauze, as well as non-hermetic cotton-gauze secured with bandages to provide light compression.

Primary limb amputations were also performed according to indications, taking into account the MESS scale score (mangled extremity severity score), which is an aid in determining the indication for limb amputation. A score ≥ 7 on the MESS scale determined the need for limb amputation in 100 % of cases.

At levels III and IV care, medical care was provided in specialized departments (clinics) involving resuscitation specialists, traumatologists, burn surgeons, and other specialists. During further treatment, staged treatment was performed taking into account PI, which included repeated surgical procedures, and multiple early necrectomies of burn wounds with the application of vacuum dressings.

A VAC-technique for wound treatment made it possible to:

a) effectively cleanse the wound contents, including substances that slow down wound healing and cause local and systemic inflammation;

b) maintain a constant temperature in the wound, reducing the effects of hypothermia and a moist wound environment (Fig. 5).

In cases of infectious complications, further surgical interventions were conducted involving extensive dissection and thorough draining of abscesses. We employed necrosequestrectomy and physical wound debridement techniques, including mechanical debridement, pulse lavage, ultrasonic cavitation, vacuum therapy, and effective limb immobilization.

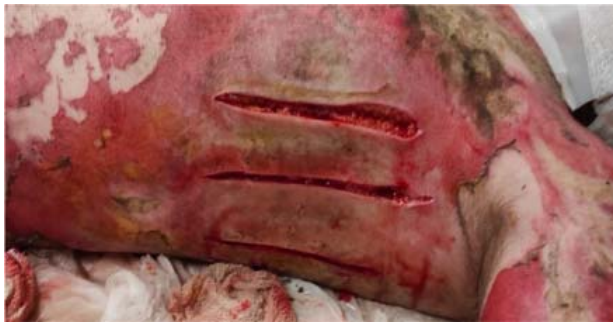

Figure 3. **Necrotomy of the injured body area in a patient with CCTMI**

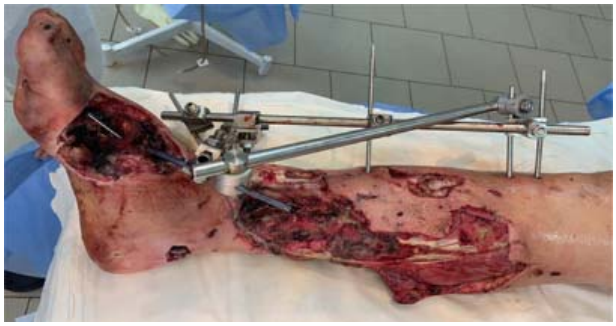

Figure 4. **Segment fixation (tibia-foot) with a rod apparatus for external fixation**

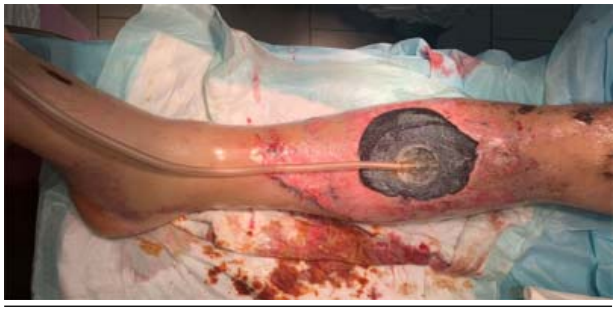

Figure 5. **VAC bandage applied to the damaged area of the lower leg**

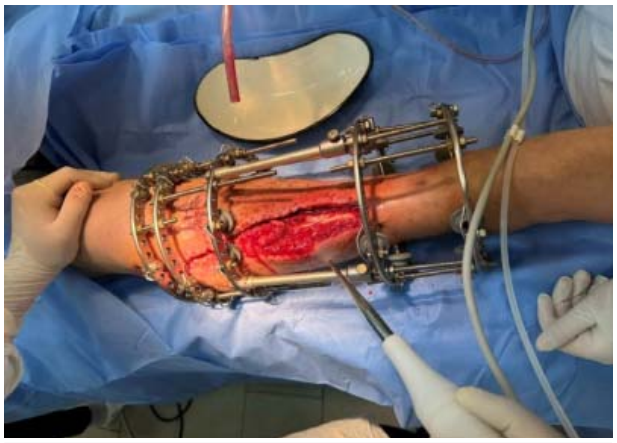

Figure 6. **Performing ultrasonic cavitation in a patient with CCTMI of the right tibia**

In the event of an extensive purulent lesion, we performed bone resection with osteosynthesis using the Ilizarov apparatus. When required, following the resolution of acute symptoms and stabilization of the patient's overall state, we conducted amputations for secondary causes and re-amputations. Various closure procedures were employed while cleaning purulent-necrotic wounds (Fig. 6).

After emergency care, rehabilitation procedures were carried out, as indicated by rehabilitation specialists, who thoroughly analysed and compiled a list of functional issues and disorders. After that, a personalized rehabilitation plan was developed. During the patient's stay in Ministry of Defence hospitals, they received rehabilitation care in inpatient departments, including intensive care units, surgery rooms, and/or dressing rooms. At level III care, the wounded individuals with CCTMI were treated in clinics for injuries or thermal trauma. Operations were performed for the same indications as at level II care. However, specialized treatment was provided by burn surgeons and traumatologists using modern diagnostic methods (spiral computed tomography and magnetic resonance imaging, angiography), medical equipment (orthopedic table, electron-optical converter, necessary instruments, and consumables), and full-scope intensive care. Repeated surgical procedures for musculoskeletal wounds were performed. With body surface area of the burn of more than 40 %, stepwise excisions were conducted over several days until all burn necrosis was excised. They were followed by temporary plastic surgery, including skin allografts or xenoderm implants and prophylactic or decompressive fasciotomy. Limbs were amputated or re-amputated based on the primary indications. Rod apparatuses for external fixation were installed to immobilize long-bone gunshot fractures for medical and transportation purposes.

Vacuum wound therapy was actively used in the treatment of gunshot wounds of soft tissues and burn wounds after necrectomy (Table 6).

Due to the extended treatment durations and the necessity for multiple surgical procedures, once injured patients with CCTMI stabilized, they were airlifted to the National Military and Medical Clinical Centre «The Main Military Clinical Hospital» for level IV care.

At level IV care, specialized therapy was administered by traumatologists, burn surgeons, plastic surgeons, and other specially qualified professionals. The surgical treatment protocol for patients with CCTMI persisted until the complete closure of soft tissue wounds, their healing, fracture consolidation, and stump formation after amputation and re-amputation. In the wounded individuals who received medical and transport immobilization, we performed the re-installation of a rod apparatus for external fixation. It was followed by the final

Table 6. **The scope of treatment interventions at level III care**

Treatment interventions	Main group (n = 91)		Control group (n = 87)		p
		SE		SE	
Repeated surgical treatment of wounds	85 (93.4 %)	2.40	72 (82.8%)	4.05	< 0.01
Fasciotomy	25 (27.5 %)	4.63	8 (9.2 %)	3.09	< 0.05
Installation/re-installation of a rod apparatus for external fixation	75 (82.4 %)	3.94	60 (69.0 %)	4.97	< 0.05
Vacuum therapy, irrigation-oxygen vacuum therapy	35 (38.5 %)	4.91	18 (20.7 %)	4.35	< 0.01
Autodermoplasty using full-thickness dermal fascial grafting with vascular pedicle flaps	18 (19.8 %)	4.02	6 (6.9 %)	2.67	< 0.05
Amputation	5 (5.5 %)	2.35	15 (17.2 %)	4.05	< 0.05

Table 7. **The scope of treatment interventions at level IV care**

Treatment interventions	Main group (n = 88)		Control group (n = 82)		p
		SE		SE	
Primary/secondary surgical treatment of wounds	79 (89.8 %)	3.28	64 (78.1 %)	4.48	< 0.05
Primary-delayed/secondary sutures	54 (61.4 %)	5.13	37 (45.1 %)	5.47	< 0.05
Re-installation of a rod apparatus for external fixation, installation of the Ilizarov apparatus using the two-stage Masquelet method	74 (84.1 %)	4.08	41 (50.0 %)	5.51	< 0.01
Conversion of osteosynthesis method	24 (27.3 %)	4.57	38 (46.3 %)	5.50	< 0.01
Vacuum therapy, irrigation-oxygen vacuum therapy	36 (40.9 %)	5.26	19 (23.2 %)	4.50	< 0.01
Ultrasound cavitation	34 (38.6 %)	5.14	18 (22.0 %)	4.50	< 0.05
Full-thickness dermal fascial grafting with vascular pedicle flaps	16 (18.2 %)	3.90	6 (7.3 %)	2.98	< 0.05
Autodermoplasty	26 (29.6 %)	4.69	13 (15.9 %)	3.97	< 0.05
Necrosequestrectomy	32 (36.4 %)	5.17	17 (20.7 %)	4.43	< 0.05
Re-amputation with a stump formation	7 (7.95 %)	2.87	17 (20.7 %)	4.48	< 0.05

repositioning of bone fragments or the dismantling and stable-functional osteosynthesis using modern medical technology as indicated (Table 7).

At level IV care, patients underwent reconstructive and restorative surgical interventions based on the principle of the «reconstructive ladder» — from simple to more complex. In the case of a long-bone defect of more than 5 cm, an antibacterial temporary cement spacer was installed using the two-stage Masquelet method (see Table 7). The temporary osteosynthesis method involving a rod apparatus for external fixation was converted into extra-focal transosseous distraction osteosynthesis using the Ilizarov apparatus.

After the final filling of the long-bone defect using the staged Masquelet method, the Ilizarov apparatus was maintained as the ultimate osteosynthesis method for at least 6 months. In the main group, this technique was used in 84.09 % ± 4.08 of cases, while in the control group, it was used in 50.00 % ± 5.51. This shows a systematic approach to osteosynthesis in the main group, especially with the emergence of notable foci after traumatic osteomyelitis. The Ilizarov apparatus was extensively used for the final treatment of the wounded in the main group, facilitating significant stability of bone fragments, even in substantial long-bone defects.

VAC therapy, irrigation-oxygen VAC therapy, and ultrasonic cavitation significantly accelerated wound healing and reduced the duration prior to suturing. If the wound could not be closed and soft tissue defects of the thigh could not be addressed by the aforementioned approaches, free autodermoplasty or plastic surgery with a rotational dermal fascial flap was performed (Fig. 7).

The treatment quality of the wounded was significantly higher in the main group than in the control group across all essential parameters, as measured by the Mattis-Lyuboszyc-Schwarzberg anatomical and functional outcome scale. The table shows statistics regarding the distribution of functional treatment outcomes in both groups. The main group had a markedly greater proportion of good functional outcomes, with 49 (56.98 %) patients, surpassing the corresponding figure in the control group, which recorded only 34 (39.08 %) patients. This disparity arises from the differentiated approach to diagnosis and treatment within the main group, alongside the implementation of modern osteosynthesis methods and the management of infectious complications.

The proportion of satisfactory results was comparable between the groups: in the main group, 31 (36.78 %) patients, and in the control group, 28 (32.18 %) patients. This indicates that even in the case of complicated injuries, the approved standards of care can yield adequate results.

The most significant difference between the groups was noted in unsatisfactory results. In the control group, there were 16 patients (18.39 %), however in the main group, there were only 6 patients (6.24 %), which is nearly three times fewer [2, 9].

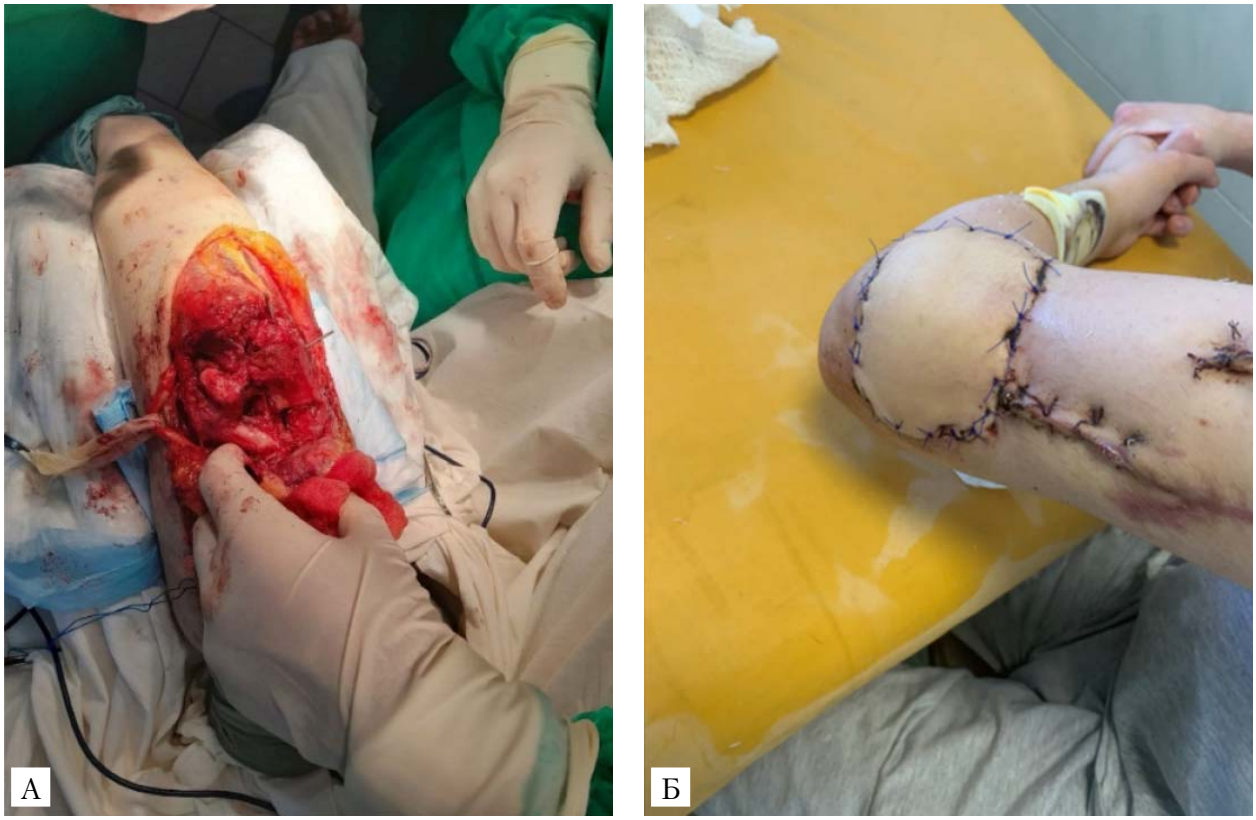

Figure 7. **Dermal fascial flap reconstruction of the soft tissue defect of the left elbow joint: before surgery (A) and after (B) surgery**

The general distribution of findings among the groups validates the statistical significance of the differences ($\chi^2 = 7.15$; $p < 0.05$). The differentiated surgical treatment strategy in the main group resulted in a nearly threefold reduction in unsatisfactory outcomes compared to the control group, confirming its effectiveness and facilitating a substantial enhancement in functional indicators (Table 8).

Complications and functional disorders in wounded individuals with long-bone gunshot fractures and CCTMI were divided into two groups: early and late.

Early complications in wounded individuals with long-bone gunshot fractures and CCTMI in comparison groups are characterized by a decrease in complications from 182.5 % in the control group to 140.1 % in the main group ($\chi^2 = 7.43$; $p < 0.01$). One of the early CCTMI complications was posthemorrhagic anemia, which occurred in 24 (26.37 %) patients in the main group and 37 (42.53 %) patients in the control group. In the main group, its frequency decreased due to active correction of blood circulation at the first levels of patient care. In some cases, anemia caused metabolic changes in the myocardium detected in 10 (10.99 %) patients in the main group and 26 (29.89 %) patients in the control group. These changes were manifested on the electrocardiogram by decreased tooth voltage and impaired myocardial repolarization (Table 9).

Table 8. **Comparison of the quality of treatment of the wounded according to the Mattis-Lyuboszyc-Schwarzberg anatomical and functional outcome scale**

Functional outcomes	Main group (n = 86)		Control group (n = 78)		Total (n = 164)	
		SE		SE		SE
Good	49 (57.0 %)	2.85	34 (39.1 %)	5.23	83 (50.6 %)	3.90
Satisfactory	31 (36.8 %)	1.84	28 (32.2 %)	5.01	59 (36.0 %)	3.75
Unsatisfactory	6 (6.2 %)	0.31	16 (18.4 %)	4.15	22 (13.4 %)	2.66

Table 9. **Early complications in the wounded with long-bone gunshot fractures and CCTMI in the comparison groups**

Complications	Main group (n = 91)	Control group (n = 87)	Total (n = 178)
Anemia	24 (26.4 %)	37 (42.5 %)	61 (34.3 %)
Metabolic changes in the myocardium	10 (10.99 %)	26 (29.9 %)	36 (20.2 %)
Acute renal failure	7 (7.69 %)	19 (21.8 %)	26 (14.6 %)
Thromboembolic complications	9 (9.9 %)	17 (19.5 %)	26 (14.6 %)
Disseminated intravascular coagulation	6 (6.59 %)	16 (18.4 %)	22 (12.4 %)
Pneumonia	18 (19.8 %)	32 (36.8 %)	50 (28.1 %)
Others	4 (4.4 %)	9 (10.3 %)	13 (7.3 %)
Total	78 (85.7 %)	156 (179.3 %)	234 (131.5 %)

Table 10. **Late complications in the wounded with long-bone gunshot fractures and CCTMI in the comparison groups**

Complications	Main group (n = 91)	Control group (n = 87)	Total (n = 178)
Post-operative wound suppuration	9 (9.9 %)	19 (21.8 %)	28 (15.7 %)
Phlegmons/abscesses	8 (8.8 %)	16 (18.4 %)	24 (13.5 %)
Osteomyelitis	6 (6.59 %)	14 (16.1 %)	20 (11.2 %)
Failed dermal grafts	5 (5.5 %)	12 (13.8 %)	17 (9.55 %)
Combined contractures of large joints	7 (7.69 %)	15 (17.2 %)	22 (12.4 %)
Re-amputation due to gangrene and osteomyelitis	4 (4.4 %)	9 (10.3 %)	13 (7.3 %)
Re-amputation for prosthetics	3 (3.3 %)	6 (6.9 %)	9 (5.1 %)
Total	42 (46.2 %)	91 (104.6 %)	133 (74.7 %)

Among the late complications (Table 10), post-operative wound suppuration and osteomyelitis remained significant challenges. However, in the main group, these complications occurred less frequently (9.89 % and 6.59 %, respectively) than in the control group (21.84 % and 16.09 %, respectively). Limb re-amputations due to gangrene or osteomyelitis were performed in 4.40 % of patients in the main group, which is significantly less than in the control group (10.34 %, $p < 0.05$) [4, 13].

The treatment duration of the wounded with long-bone gunshot fractures and CCTMI who survived reveals considerable benefits of the treatment strategy in the main group. The main group had an average hospitalization stay of 18.6 ± 2.0 days, compared to the control group's 23.4 ± 2.5 days, which was 20.5 % longer. The average treatment duration for mild wounds was 12.5 ± 1.2 days in the main group and 14.8 ± 1.5 days in the control group, with no recorded deaths. Inpatient care for severe wounds was reduced by 19.6 % in the main group (21.3 ± 2.3 vs. 26.5 ± 2.7 days), resulting in a drop in mortality from 14.3 % to 7.1 %. The average treatment duration for extremely severe injuries was reduced by 25.7 % (30.4 ± 3.1 days vs. 38.2 ± 3.8 days in the control group), and mortality decreased by 38.9 % (from 27.3 % to 16.7 %). The control group had a mortality rate of 10.3 % (9 cases), while the main group had only 5.5 % (5 cases) ($p < 0.05$). These findings support the effectiveness of a differentiated surgical treatment strategy in the main group, which reduces inpatient duration, lowers the probability of fatal cases, and improves clinical outcomes.

Conclusions

Based on a differentiated approach to the surgical treatment of long-bone gunshot fractures, we have substantiated, developed, and implemented an algorithm for osteosynthesis in wounded individuals with long-bone fractures and CCTMI at levels III and IV care. This strategy improved the functional treatment outcomes according to the Mattis-Lyuboshyts-Schwarzberg scale. It resulted in an increase in the proportion of good results from 39.08 ± 5.23 % to 56.98 ± 2.85 %, with a decrease in the relative number of unsatisfactory results from 18.39 ± 4.15 % to 6.24 ± 0.31 %, at $p < 0.05$.

A differentiated surgical strategy with an objective assessment of injury severity at different levels of patient care resulted in a decrease in mortality from 10.34 % in the control group to 5.49 % in the main group, reflecting a reduction of 4.85 %, the proportion of persistent contractures from 17.24 % to 7.69 %, rejection of dermal grafts from 13.79 % to 5.49 %, osteomyelitis from 16.09 % to 6.59 %, re-amputations of limbs from 6.90 % to 3.30 %, and hospital stay from 23.4 ± 2.5 to 18.6 ± 2.0 days, which is 20.5 % less ($p < 0.05$).

Declaration of interests

The authors declare no potential conflicts of interest.

Funding. The authors did not receive any additional financial support.

Ethics approval and written informed consent 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, formalization, conclusions; I. P. Palii, O. I. Zhovtonozhko, V. S. Honcharuk: design, materials and methods, data processing, statistics.

References

1. Braun J, Gertz SD, Furer A, et al. The promising future of drones in prehospital medical care and its application to battlefield medicine. J Trauma Acute Care Surg. 2019;87(1S Suppl 1):S28-S34. https://doi.org/10.1097/TA.0000000000002221.
2. Edwards MJ, Lustik M, Eichelberger MR, et al. Blast injury in children: an analysis from Afghanistan and Iraq, 2002-2010. J Trauma Acute Care Surg. 2012;73(5):1278-83. https://doi.org/10.1097/TA.0b013e318270d3ee.
3. Kobayashi K. Damage control surgery – a historical view. Nippon Geka Gakkai Zasshi. 2002;103(7):500-2.
4. Kuchyn IL, Horoshko VR. Predictors of treatment failure among patients with gunshot wounds and post-traumatic stress disorder. BMC Anesthesiol. 2021;21(1):263. https://doi.org/10.1186/s12871-021-01482-8.
5. Lindholm C, Searle R. Wound management for the 21st century: combining effectiveness and efficiency. Int Wound J. 2016;13(Suppl 2):5-15.
6. Liu D, Huang SY, Sun JH, et al. Sepsis-induced immunosuppression: mechanisms, diagnosis and current treatment options. Mil Med Res. 2022;9(1):56. https://doi.org/10.1186/s40779-022-00422-y.
7. Martin R, Taylor S, Palmieri TL. Mortality following combined burn and traumatic brain injuries: An analysis of the national trauma data bank of the American College of Surgeons. Burns. 2020;46(6):1289296. https://doi.org/10.1016/j.burns.2020.06.022.
8. Obst W, Esser T, Kaasch AJ, et al. The need of antimicrobial stewardship in post-operative infectious complications of abdominal surgery. Visc Med. 2022;38(5):345-53. https://doi.org/10.1159/000526785.
9. Sandhu A, Claireaux HA, Downes G, Grundy N, Naumann DN. Emergency first responder management of combat injuries to the torso in the military, remote and austere settings. BMJ Mil Health. 2022;168(6):478-82. https://doi.org/10.1136/bmjmilitary-2020-001460.
10. Skube ME, Mallery Q, Lusczek E, Elterman J, Spott MA, Beilman GJ. Characteristics of combat-associated small bowel injuries. Mil Med. 2018;183(9-10):e454-e459. https://doi.org/10.1093/milmed/usy009.
11. Sugrue M, D'Amours SK, Joshipura M. Damage control surgery and the abdomen. Injury. 2004;35(7):642-48. https://doi.org/10.1016/j.injury.2004.03.011.
12. Treadwell JR, Lucas S, Tsou AY. Surgical checklists: a systematic review of impacts and implementation. BMJ Qual Saf. 2014;23(4):299-318. https://doi.org/10.1136/bmjqs-2012-001797.
13. Walsh TJ, Hospenthal DR, Petraitis V, Kontoyiannis DP. Necrotizing mucormycosis of wounds following combat injuries, natural disasters, burns, and other trauma. J Fungi (Basel). 2019;5(3):57. https://doi.org/10.3390/jof5030057.
14. Widgerow AD, King K, Tocco-Tussardi I, et al. The burn wound exudate-an under-utilized resource. Burns. 2015 Feb;41(1):11-7. https://doi.org/10.1016/j.burns.2014.06.002.
15. Yongqiang Z, Dousheng H, Yanning L, Xin M, Kunping W. Peacekeepers suffered combat-related injuries in Mali: a retrospective, descriptive study. BMJ Mil Health. 2020;166(3):161-6. https://doi.org/10.1136/jramc-2018-001010.

Особливості диференційованого хірургічного лікування поранених із бойовою комбінованою термомеханічною травмою та вогнепальними переломами довгих кісток за рівнями медичного забезпечення

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Мета — покращити результати лікування поранених з переломами довгих кісток при бойовій комбінованій термомеханічній травмі (БКТМТ) шляхом розробки та впровадження диференційованої хірургічної тактики на різних рівнях медичного забезпечення.

Матеріали та методи. Проаналізовано результати хірургічного лікування 178 поранених з переломами довгих кісток та БКТМТ. У дослідженні використано загальноклінічні, хірургічні, лабораторні, біохімічні, морфологічні і статистичні методи. Поранені були розподілені на дві клінічні групи порівняння — основну та контрольну. Основна група включала 91 пораненого з вогнепальними переломами довгих кісток, яким хірургічне лікування проводили за диференційованою хірургічною тактикою, з урахуванням тяжкості БКТМТ. Та контрольна група, яка включала 87 поранених з вогнепальними переломами довгих кісток при БКТМТ, яким хірургічне лікування проводили з використанням традиційних методів лікування опікових та вогнепальних ран. Порівняння проводили за віком, питомою вагою вогнепальних переломів довгих кісток, опікових поверхонь, видом ранового каналу, кількістю ран, видом травми, терміном поступлення, аналізу ефективності організаційно-лікувальних заходів ($p > 0,05$).

Результати. Аналіз лікувальних заходів показав, що в основній групі частота виконання фасціотомій становила 27,47 %, тоді як у контрольній — лише 9,20 %, а виконання вакуумної терапії досягало 40,91 порівняно з 23,17 % у контрольній групі ($p < 0,05$). Використання сучасних підходів у фіксації уламків при БКТМТ з значними дефектами кісток, зокрема апаратів Ілізарова, з використанням двоетапної методики Masquelet також було значно поширенішим в основній групі (84,09 порівняно з 50,00 %, $p < 0,01$). Застосування шкали AdTS-CTMT та перфузійного індексу в усіх випадках основної групи сприяло своєчасній оцінці стану пацієнта, що дозволило підвищити якість лікування та уникнути ускладнень. Щодо ранніх ускладнень, частота анемії була значно нижчою в основній групі (62,64 порівняно з 78,16 %, $p < 0,05$), що сприяло зменшенню метаболічних змін міокарда (23,08 порівняно з 36,78 %) та гострої ниркової недостатності (9,89 порівняно з 14,94 %). Частота тромбоемболічних ускладнень у контрольній групі була майже вдвічі вищою (12,64 порівняно з 7,69 %, $p < 0,05$), що вказує на недосконалість профілактичних заходів. Серед пізніх ускладнень суттєвим викликом залишалися нагноєння післяопераційних ран та остеомієліт, однак у пацієнтів основної групи ці ускладнення зустрічалися рідше (9,89 % та 6,59 % відповідно), ніж у контрольній (21,84 та 16,09 %). Реампутації кінцівок через гангрену чи остеомієліт проводилися у 4,40 % пацієнтів основної групи, що значно менше ніж у контрольній (10,34 %, $p < 0,05$).

Висновки. Функціональні результати лікування за шкалою Маттіса—Любошиця—Шварцберга: збільшена питома вага добрих результатів — з (39,08 ± 5,23) до (56,98 ± 2,85) %, зменшена відносна кількість незадовільних — з (18,39 ± 4,15) до (6,24 ± 0,31) %, при $p < 0,05$. Впровадження диференційованої хірургічної тактики з урахуванням тяжкості травми на рівнях медичного забезпечення дозволило зменшити рівень летальності з 10,34 % контрольної групи до 5,49 % основної, різниця знизилась на 4,85 %.

Ключові слова: бойова комбінована термомеханічна травма, вогнепальне поранення, політравма, синдром взаємного обтяження, травматична хвороба, травматичний шок, опіки.

FOR CITATION

Korol SO, Palii IP, Zhovtonozhko OI, Honcharuk VS. Peculiarities of a differentiated approach to surgical treatment of patients with combined combat thermomechanical injuries and long-bone gunshot fractures by the levels of patient care. General Surgery (Ukraine). 2024:(4);8-19. http://doi.org/10.30978/GS-2024-4-8.