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Treatment of limb combat blast wounds using negative pressure

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Blast injury (BI) is a combat multifactorial injury resulting from the impulse action of the complex traumatic factors by the mine munition explosion, characterized an interconnected and increasingly severe impact, massive deep tissue damage and the development of a general contusion-shock syndrome. For severe BI with large skin and soft tissue defects, it is advisable to use negative pressure wound therapy (NPWT). Objective. To analyze the effectiveness of using the NPWT system in patients with blast injuries. Methods. Publications were searched in electronic systems Google Scholar, PubMed, ScienceDirect, archives of specialized journals. The results of treatment using NPWT of 134 patients were analyzed: 130 (97 %) men and 4 (3 %) women, average age 36.6 years (22–64). According to the types of injuries, the patients were distributed as follows: blast injury — 128 (95.5%), bullet injuries — 6 (4.5 %). The results. The goal of BI treatment by negative pressure is to improve wound healing through multiple mechanisms of action at the macroscopic and microscopic levels. The use of NPWT reduces the risk of infectious complications, prevents excessive progression necrosis of affected tissues, accelerates the growth of granulation tissues and reduces pain syndrome. The result of the treatment is the wound preparation for primary healing or, in the case of significant soft tissue damage, the creation of favorable conditions for performing plastic surgeries. In general, NPWT accelerates treatment times, reduces risks of complication level and improves functional results. This current own research coincides with the results of majority authors and allows us to continue work in this direction. Conclusions. Treatment of blast injury wounds with the use of vacuum bandages and devices for creating negative pressure is an effective approach that contributes to the reduction of infectious complications, the growth of granulation tissue, facilitates further skin plasticity of the defect, accelerates the recovery time of the wounded and his rehabilitation.

Вибухове поранення (ВП) — це бойове багатофакторне ураження внаслідок імпульсної дії комплексу травмувальних чинників вибуху мінного боєприпасу, характеризується взаємопов'язаним і чимраз тяжчим впливом, масивними глибокими ушкодженнями тканин і розвитком загального контузійно-комоційного синдрому. За важких ВП із великими дефектами шкіри та м'яких тканин, доцільно використовувати лікування ран негативним тиском (ЛРНТ). Мета. Проаналізувати ефективність використання системи ЛРНТ у пацієнтів із вибуховими пораненнями. Методи. Проведено пошук публікацій в електронних системах Google Scholar, PubMed, ScienceDirect, архівах спеціалізованих журналів. Проаналізовано результати лікування з використанням ЛРНТ 134 пацієнтів: 130 (97 %) чоловіків і 4 (3 %) жінки, середній вік 36,6 року (22–64). За видами поранень пацієнти розподілилися так: вибухова травма — 128 (95,5 %), кульові — 6 (4,5 %). Результати. Мета лікування ВП негативним тиском — покращити загоєння ран завдяки численним механізмам дії на макроскопічному та мікроскопічному рівнях. Використання ЛРНТ зменшує ризик інфекційних ускладнень, запобігає надмірному прогресуванню некрозу вражених тканин, прискорює ріст грануляційних тканин і зменшує больовий синдром. Результатом лікування є підготовка рани для загоєння первинним натягом або, в разі значного ушкодження м'яких тканин, створення сприятливих умов для виконання пластичних утручань. Загалом, ЛРНТ прискорює терміни лікування, знижує ризики ускладнень і покращує функціональні результати. Власні дослідження з лікування ран негативним тиском співпадають із результатами більшості авторів та дозволяють продовжувати роботу в цьому напрямі. Висновки. Лікування вибухових поранень зі застосуванням вакуумних пов'язок і пристроїв для створення негативного тиску є ефективним підходом, який сприяє зменшенню інфекційних ускладнень, росту грануляційної тканини, полегшує подальшу шкірну пластику дефекту, прискорює час одужання пораненого та його реабілітацію. Ключові слова. Вибухове поранення, дефекти м'яких тканин кінцівок, терапія негативним тиском, лікування ран.

Key words. Blast injury, soft tissue defects of limbs, negative pressure therapy, wound treatment

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Introduction

Blast injury (BI) is a combat multifactorial injury resulting from an impulse action of a complex of traumatic factors of a munition explosion, characterized by an interconnected and increasingly severe impact, with massive deep tissue damage and the development of a general contusion-shock syndrome. Traumatic agents are mostly shock waves, high temperature and flame, shrapnel and secondary striking metal fragments, toxic effect of gaseous explosion products, sound (acoustic trauma) [1].

As a result of explosive injuries, there are three zones of changes in the injured tissues, namely: detachment, crushing and exfoliation of tissues; contusions; concussions (structural changes in blood vessels and nervous anatomical formations).

Assessment of information on military trauma over the past decades showed an increase in the number of blast injuries: World War II — 2.7 %; war in Vietnam — 12.6 %; Afghanistan — 25.0 %, and according to the Institute of Surgical Research of the US Army, during military operations in the period 2003–2006 the share of BI was as high as 49 % [2].

The increase in the number of high-energy and blast wounds determines the use of modern methods of wound treatment. For severe BI, accompanied by large skin and soft tissue defects, it is advisable to use negative pressure wound treatment (NPWT), provided by a vacuum assisted closure (VAC). The system consists of a foam sponge with open pores, which is placed in the wound, an adhesive hermetic bandage and a vacuum pump that creates negative pressure in the wound [3]. Negative pressure treatment improves wound healing due to numerous mechanisms of action at both the macroscopic and microscopic levels [4, 5]. The main ones are:

– *macrodeformation of the wound* — depending on the deformation of the adjacent tissues, the edges of the wound are brought closer to each other with the help of suction distributed through a foam sponge. This reduces the space required for cure by primary healing or secondary granulation formation;

– *microdeformation of the wound surface* — promotes cell proliferation, local release of growth factors and angiogenesis. This mechanism of action is investigated using a mathematical finite-element model. It has been proven that due to the application of VAC, the elements are deformed by 5–20 %. This corresponds to the necessary level of deformation in the culture for the proliferation of cells due to NPWT stress in the healing tissues [6];

– *removing exudate from the extracellular space* — removal of inflammatory mediators and cytokines, the prolonged action of which can interfere with the ability to support damaged tissue and can lead to further necrosis, which is often observed during wound treatment;

– *creating a warm and moist environment* — preventing the wound from drying out and increasing the formation of granulation tissue [7].

The negative pressure system was first introduced in the 19th century for performing complex thoracic operations while avoiding lung collapse. The device was miniaturized by surgeons during the First World War. Dr. Sauerbruch invented a portable dome that was worn over the chest, isolating only the surgeon's chest and hands. Several clinical notes of the author in his autobiography testify to the further improvement of the domes and their use for the treatment of infected wounds, mainly on the legs [8].

The idea gained a new development when M. J. Morykwas et al. [9] reported the results of animal studies. They used a pig model, closed the wound with asponge with open pores, and then with an adhesive tape, exposed to a pressure of –125 mmHg. A fourfold increase in blood flow and a significant increase in the rate of formation of granulation tissue were detected. A decrease in the number of bacteria in the tissues and an increase in the survival of the skin piece by 21 % compared to the control were also recorded. The authors concluded that controlled pressure below atmospheric creates favorable conditions for wound healing [9].

The purpose of the study: to analyze the effectiveness of the negative pressure wound treatment system in patients with blast injuries.

Material and methods

In order to assess the efficiency of using the negative pressure wound treatment system, publications were searched in electronic systems Google Scholar, PubMed, ScienceDirect, archives of specialized journals.

The study involved evaluation of the outcomes of treatment of 20 patients with blast and gunshot injuries treated in the combat trauma department of the State Institution Professor M. I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Medical Sciences of Ukraine and 114 patients with military trauma, treated in the surgical department of the Municipal Budgetary Establishment Pervomayskaya Central District Hospital of Kharkiv region during the period from the beginning of Russian military aggression in Ukraine from February to September 2022.

In total, 134 patients received specialized medical care in both medical institutions: 130 (97 %) men and 4 (3 %) women, the average age was 36.6 years (22–64). According to the types of injuries, the patients were divided as follows: blast injury — 128 (95.5 %), gunshot injuries — 6 (4.5 %). At the first stage of treatment, most subjects in this category underwent primary surgical treatment of the wound, removal of foreign bodies (if any), primary stabilization of limb fractures with external fixation devices, hemostasis, wound drainage and dressings for 3–4 days with ointment containing antibiotics. If necessary, staged necrectomy was performed, after which, according to the indications, secondary sutures or the VAC system were applied to the wound, followed by plastic closure of the wound defect. During NPWT, bandages were changed 4–5 times every 3–4 days along with simultaneous staged necrectomy.

The research materials were discussed and approved by the Bioethics Committee at the State Institution Professor M. I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Medical Sciences of Ukraine (Protocol No. 227 of 28.10.2022).

Results and their discussion

The main principles of treatment of BI are primary surgical treatment of the wound, removal of necrotic and contaminated tissues, drainage and prevention of infectious complications. The wound is left open, dressings with antiseptics are applied and, in the absence of purulent-necrotic complications, sutures are performed in a few days or the wound is closed with the help of various types of skin repair. In the case of a fracture, it is revised, free bone fragments are removed and stabilized with an external fixation device [10]. BIs can have a large number of fragments. During primary surgical repair of wounds, intra-articular fragments and those that are potentially harmful to other anatomical structures due to their location should be removed [11].

The International Committee of the Red Cross (ICRC) proposed the ICRC classification of explosive injuries, which has an evaluation system based on six parameters:

E — entrance wound, maximum diameter in centimeters;

X — exit wound, maximum diameter in centimeters (0, if there is no exit wound);

C — cavity defect 0–1 (can accommodate two fingers of the surgeon;

F — fracture 0–2 (no fracture, simple fracture / hole / slight crushing / significant crushing);

V — damage to vital structures 0–1 (dura mater, pleura, peritoneum, damage to large vessels);

M — metal fragments 0–2 (none, one fragment, several fragments).

Thus, a typical blast injury can be presented as E4 X0 C1 F0 V1 M2 [12].

In case of severe wounds (accompanied by significant defects of the skin and soft tissues, which make it difficult or impossible to close the wound for healing by primary tension, requiring plastic surgery in further treatment, with a high risk of infection), it is advisable to use a system for treating wounds with negative pressure.

To date, all NPWT systems have a similar design with a pump located in the main unit and providing negative pressure in the wound, a canister for collecting wound drainage, and a tube that connects it to the hermetically sealed wound. The NPWT device functions by rendering and evenly distributing negative pressure in the wound through the use of a sponge or gauze bandage [13]. Both foam sponge and gauze have been shown to be equally effective for wound healing and blood flow stimulation [14]. According to D. Armstrong et al. [15], the sponge provides rapid growth of granulations, but instead, its ingrowth is observed, which can potentially disrupt the process of epithelization, as well as be painful during the replacement of the sponge [16–19].

Base unit pumps can be adjusted to different pressures and usually have two settings: constant and intermittent. Wounds with a high amount of exudate require continuous suction and a lower pressure setting [20]. Most often, a constant pressure of –80 up to –125 mmHg is used.

NPWT requires regular wound care. There are no fixed intervals for ligation and they can vary from 2 to 4 days [21]. This variation in dressing change is due to the nature of the wound and degree of contamination. E. Shweiki et al. [22] reported a safe and effective interval for the next dressing change after initial application in acutely contaminated wounds. They came to the conclusion that this interval should comprise 1.7–4.1 days (2.9 on average).

Successful NPWT is characterized by a change in the color and amount of exudate. The volume of exudate should gradually decrease and the color should change from bloody to serous-bloody. The appearance of the wound will change to red, along with the formation of granulation tissue in it. The velvety color of the wound indicates the growth of granulations in the sponge. The size of the wound should gradually decrease, and a new epithelium can be seen at its edge [23].

A number of studies have been published about the benefits of using NPWT in combat injuries [24, 25]. In favor of NPWT is the fact that during Operation Enduring Freedom (OEF) during the war in Iraq, in a six-month period, the number of cases of VAC therapy almost doubled, from 46 % of wounds treated with NPWT to more than 90 % [26]. The technique quickly gained popularity among military surgeons worldwide due to its versatility, ease of use, and diverse indications for combat-related injuries. NPWT has become a better method for combat injuries compared to the traditional use of saline-soaked bandages. Further technical improvements confirmed its effectiveness during air transport, allowing the injured to receive continuous NPWT during air evacuation from an advanced surgical center to a tertiary care facility [27].

S. Maurya et al. [23] conducted a study of the effectiveness of VAC therapy in the area of the foot and supracalcaneal joint on the example of 17 combatants with blast injuries. Wound debridement was followed by NPWT and the foot defect was adequately reconstructed using split skin graft, skin-fascial or free microvascular grafts. The average time to the final reconstructive procedure was 16.5 days. According to the authors, NPWT helped prevent amputations resulting from blast injury and was useful for satisfactory reconstruction of foot defects. All soldiers were rehabilitated and returned to their units and were able to perform their duties without significant physical exertion.

B. E. Leininger et al. [28] reported their experience with NPWT for contaminated soft tissue injuries in Iraq in 77 patients (88 wounds). Despite high-energy soft tissue wounds, no cases of infection or general wound complications were found. This was associated with early wound management and lavage and reduced hospital stay due to NPWT. In another study published by M. A. Peck et al. [29] infectious complications were recorded in only 4 % of cases in the event of NPWT.

S. Geiger et al. [26] in 2008 conducted a retrospective study of the outcomes of treatment of 68 patients who underwent 240 operations between April 2003 and December 2005. Most of the injuries were blast (55 %) and gunshot (19 %). Extremity lesions comprised 91.2%, the ratio of the number of lower extremity wounds to the upper one was approximately 2:1. Wound treatment tactics included thorough initial surgical debridement (ISD), antibiotics, and the use of NPWT. The percentage of limb preservation was high and amounted to 93.6 %, three amputations were performed due to insufficiency of the piece. The incidence of acute osteomyelitis was 24.2 %, chronic — 1.6 %.

The authors noted a higher rate of limb preservation than that achieved in previous wars and noted that their success was due to the use of NPWT, the only novel intervention among the authors' proposed treatment of combat wounds.

Only minor complications following NPWT in combat wounds have been reported in the literature. This may be due to the nature of the wounds treated with negative pressure, and most complications were caused by bleeding or infections [30].

All patients of the analyzed group, depending on the type of injury, received care that included stabilization of the general condition, analgesia, antibacterial prophylaxis, primary surgical treatment of wounds with the removal of foreign bodies, fragments, necrotized tissues, and drainage. Fractures of the bones of the limbs were stabilized with the help of a plaster bandage or an external fixation device. After ISD, open wounds were closed with bandages with antibiotic ointment, which were changed daily for 3–4 days. During dressings, the general appearance of the wound, the presence of exudate, and signs of inflammation were assessed. In the presence of significant integumentary tissue defects, the patients underwent staged treatment, which included mandatory application of negative pressure, step-by-step necrectomy, if necessary, and closure of wound defects using various plastic surgery techniques.

Clinical example No. 1

A 36-year-old patient T. was admitted to the surgical department 6 hours after getting an exit BI of the middle third of the thigh, E4 X15 C1 F0 V0 M0 according to the ICRC classification with a 2 cm wide skin isthmus and signs of ischemia. The first stage involved ISD and removal of necrotic tissues (Fig. 1, a), hemostasis and application of an aseptic ointment bandage with an antibiotic, which was changed daily for 4 days. Staged necrectomy was performed during dressings. On the 5th day, the wound was closed with a bandage for NPWT with a sponge, which was inserted under the isthmus and brought to the site of the entrance wound (Fig. 1, b). After applying the bandage for NPWT, pain on the VAS decreased from 8 to 3 points. The vacuum bandage was replaced every 72 hours, a total of 4 replacements were performed. During each dressing change, the condition of the wound was assessed: the depth of the injury gradually decreased, the muscles regained their elasticity, and their color normalized (Fig. 1, c, d). On the side of the isthmus, moderate positive time course was initially observed, but after 4 replacements of the vacuum bandage, skin necrosis was detected and excised. The mobility of the covering tissues around the wound became greater, which made it possible to apply 8-shaped secondary sutures with a monofilament thread (Fig. 1, e). The wound healed with primary tension.

Clinical example No. 2

A 48-year-old patient P. was admitted to the surgical department 5 hours after an exit BI of the upper third of the right shoulder with significant damage to the deltoid muscle, a round skin defect in the area of the exit hole with a diameter of 5 cm, E3 X5 C1 F0 V0 M0 according to the ICRC classification (Fig. 2, a, b). The first stage comprised ISD, drainage, hemostasis, and application of an aseptic bandage with an antibiotic. On the 5th day of treatment, a vacuum bandage with a sponge was applied to the entire depth of the wound; the wound was sutured on the back surface of the shoulder (Fig. 2, c). After that, the pain syndrome decreased from 8 to 3 VAS points. In total, 4 bandage changes were performed every 72 hours with constant revision of the wound to prevent formation of cavities between the shoulder muscles and necrectomy sites (Fig. 2, d). At the last stage, no exudate was observed and secondary sutures were applied to the wound (Fig. 2, e, f).

Clinical example No. 3

A 35-year-old female patient R. was hospitalized 4 days after admission to another medical institution, where a fracture of the distal part of the lower leg was stabilized with a «shin – foot» rod device and suturing of the wound, E10 X0 C1 F2 V0 M0 according to the ICRC classification.

During the examination, the appearance of the wound was classified as unsatisfactory. Soft tissues were swollen, gray in color with signs of necrosis, characteristic smell. One of the rods was directly in the wound (Fig. 3, a). The sutures and the rod were removed, deep soft tissue necrosis and tendon damage were visualized. Nonviable tissues and bone fragments were excised, the wound was thoroughly irrigated with antiseptic solutions (Fig. 3, b), and a bandage for NPWT was applied (Fig. 3, c). Following four changes of bandages every 72 hours, positive time course was observed, the wound was cleaned and filled with a significant amount of granulation tissue (Fig. 3, d). For the next stage of treatment, the patient was transferred to the State Institution Professor M. I. Sytenko Institute of Spine and Joint Pathology

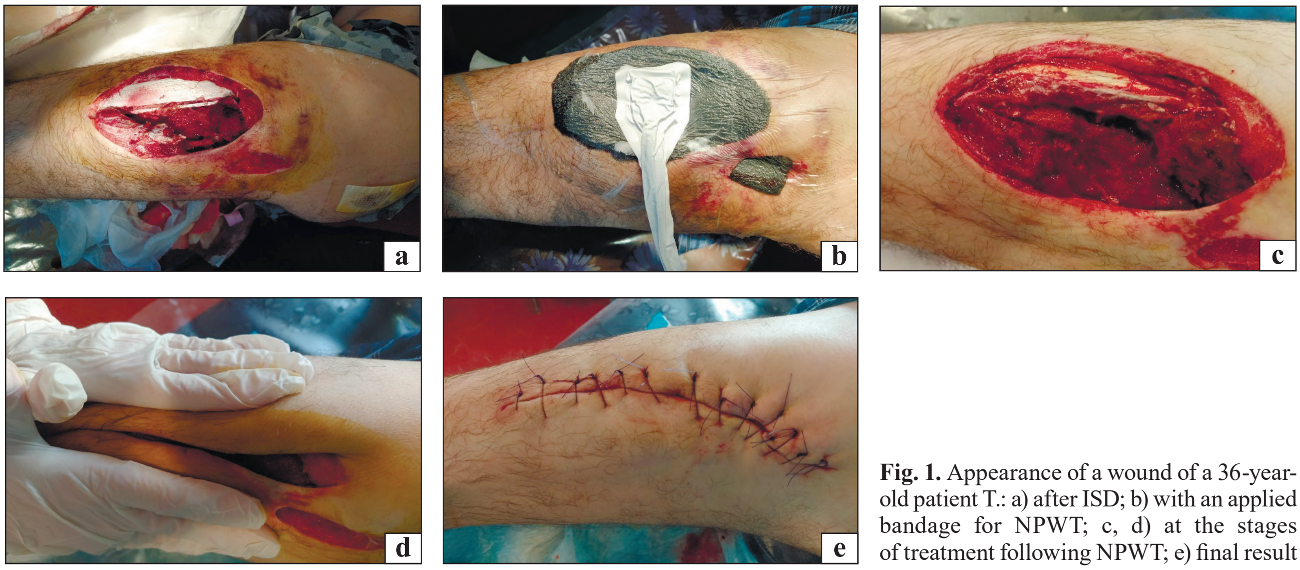

Fig. 1. Appearance of a wound of a 36-year-old patient T.: a) after ISD; b) with an applied bandage for NPWT; c, d) at the stages of treatment following NPWT; e) final result

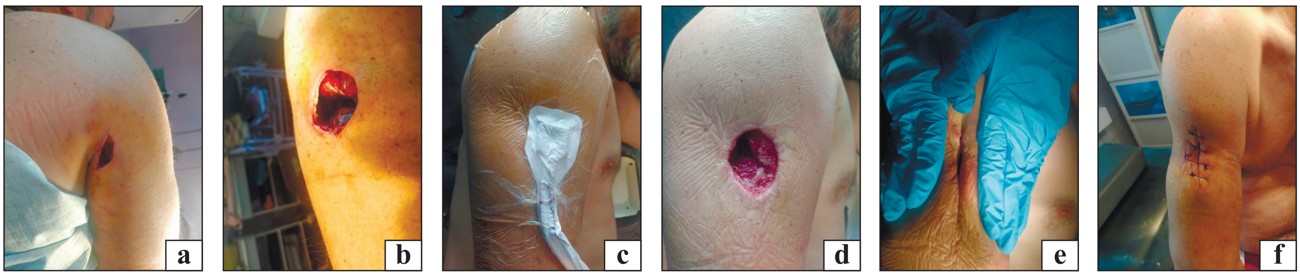

Fig. 2. Appearance of wounds of a 48-year-old patient P.: a, b) after ISD; c) with a bandage for NPWT; d, e) following NPWT; f) final result

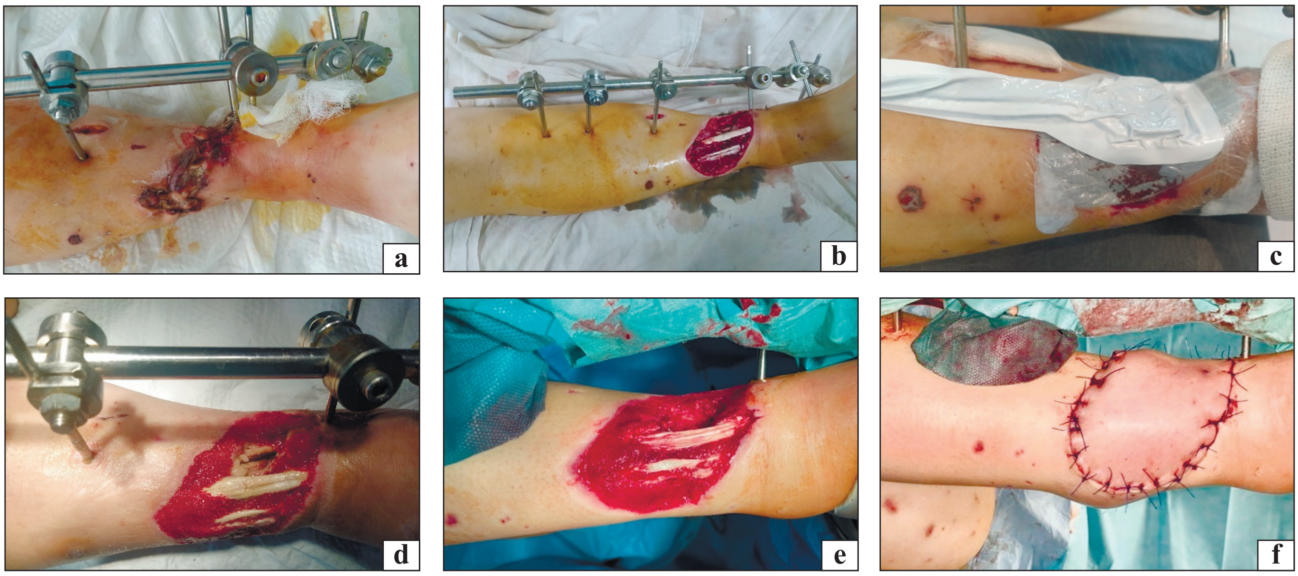

Fig. 3. Appearance of wounds of a 35-year-old patient R.: a) at the time of admission to the surgical hospital; b) after necrectomy; c) with an applied bandage for NPWT; d) following NPWT; e) before plastic surgery with a sural skin piece; f) following plastic surgery

Fig. 4. Appearance of wounds of a 28-year-old patient N.: a) at the time of admission to the hospital; b) after staged necrectomy and negative pressure treatment for 14 days; c) at the stages of operation; d) following plastic surgery of a soft tissue defect with a sural piece; e) following removal of sutures on the 21st day after surgery

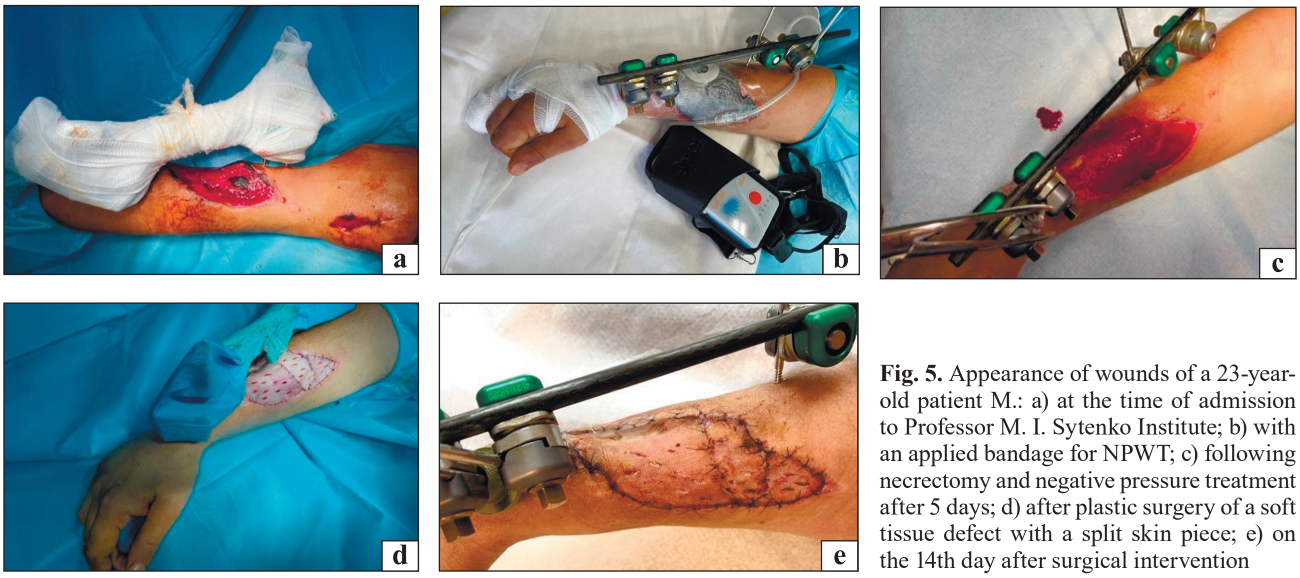

Fig. 5. Appearance of wounds of a 23-year-old patient M.: a) at the time of admission to Professor M. I. Sytenko Institute; b) with an applied bandage for NPWT; c) following necrectomy and negative pressure treatment after 5 days; d) after plastic surgery of a soft tissue defect with a split skin piece; e) on the 14th day after surgical intervention

of the National Academy of Medical Sciences of Ukraine, where she underwent a sequestrenectomy of the lower third of the right tibia and replacement of the soft tissue defect of the front surface of the right leg with a sural skin-fascial piece on the vascular pedicle (Fig. 3 e, f).

Clinical example No. 4

A 28-year-old patient N. was admitted to the Department of Emergency Traumatology and Reconstructive Surgery of the State Institution Professor M. I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Medical Sciences of Ukraine on the 7th day after the injury, E11 X0 C1 F2 V0 M0 according to the ICRC classification (Fig. 4, a). From the history, it was known that at the first stage of medical care, the patient was treated for a gunshot wound, and an external fixation device based on rods was mounted to stabilize the fracture of the right tibia. At the next stage of treatment, repeated surgical treatment of gunshot wounds was carried out in another medical institution and bandages for NPWT were applied.

At the third stage of treatment at Professor M. I. Sytenko Institute, the patient underwent staged necrectomy and replacement of dressings for NPWT with a sponge every 72 hours for 14 days. Gradually, with each necrectomy and ligation, a significant cleaning and filling of the wound with a sufficient amount of granulation tissue (Fig. 4, b) was achieved, which made it possible to perform a surgical intervention to replace the soft tissue defect with a sural skin-fascial piece (Fig. 4, c–e).

Clinical example No. 5

A 23-year-old patient M. was hospitalized to the Department of Emergency Traumatology and Reconstructive Surgery of Professor M. I. Sytenko Institute on the 15th day after getting a bullet wound, E8 X0 C1 F2 V0 M0 according to the ICRC classification (Fig. 5, b, a). At the first stage of medical care, he underwent ISD of the gunshot wound and dressings. After evacuation, at the next stage of treatment, an external fixation device was mounted on the base of the rods to stabilize the fracture of the radius of the right forearm, and the fractures of the IV and V metacarpal bones were repositioned, and metal-osteosynthesis with needles was performed. Then the patient was transferred to Professor M. I. Sytenko Institute. Due to the uneven edges of the gunshot wound, areas of necrotic tissue, insufficient amount of granulation tissue, the patient underwent revision, necrectomy, application of a bandage with a sponge for the treatment of the wound with negative pressure, repeated closed reposition with subsequent remounting of an external fixation device on the right forearm (Fig. 5, b). In 5 days, a significant cleaning and filling of the wound with a sufficient amount of granulation tissue was achieved (Fig. 5, c), which made it possible to perform a surgical intervention to replace the soft tissue defect of the right forearm with a split skin piece (Fig. 5, d).

Conclusions

Blast injuries are multifactorial wounds characterized by severe damage to adjacent tissues, requiring strict adherence to the rules of wound care during their treatment and administration of modern methods of care. The use of vacuum dressings contributes to the reduction of infectious complications, the growth of granulation tissue, facilitates further repair of the skin defect, accelerates the recovery time of the wounded and their rehabilitation. The positive results of BI treatment obtained by various authors with the help of devices for the treatment of wounds with negative pressure and our own experience confirm its effectiveness.

Conflict of interest. The authors declare no conflict of interest.

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TREATMENT OF LIMB COMBAT BLAST WOUNDS USING NEGATIVE PRESSURE

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