https://doi.org/10.23873/2074-0506-2025-17-1-76-89

Problems of surgical treatment of full-thickness burns[1]

T.G. Spiridonova✉[1], E.A. Zhirkova[1], A.V. Sachkov[1],
M.L. Rogal[1], S.S. Petrikov[1,2]

[1]N.V. Sklifosovsky Research Institute for Emergency Medicine,
3 Bolshaya Sukharevskaya Sq., Moscow 129090 Russia;
[2] Department of Anesthesiology, Intensive Care and Emergency Medicine,
Russian University of Medicine,
4 Dolgorukovskaya St., Moscow 127006 Russia

✉Corresponding author: Tamara G. Spiridonova, Dr. Sci. (Med.), Scientific Consultant of the Department of Acute Thermal Injury, N.V. Sklifosovsky Research Institute for Emergency Medicine, spiridonovatg@sklif.mos.ru

Abstract

Background. *Patients with full-thickness burns require surgical treatment, but the timing and scope of surgical interventions have not yet been defined.*

Objective. *To analyze the world experience of surgical treatment of full-thickness burns.*

Material and methods. *The literature sources on the topic were searched for in the electronic databases: PubMed, Scopus, CrossRef for the period from 1947–2023. The work includes some early basic publications on the surgical treatment of full-thickness burns; the current state of the problem has been analyzed in articles over the recent 20 years.*

Conclusion. *Data from foreign literature sources show that in low-income countries, the efficacy of early surgical excision has not been confirmed, which can be attributed to the lack of burn departments, donor blood, wound dressings. In developed countries of Europe, the*

USA, Japan, active surgical tactics are currently used and it is a rule to perform surgical excision on the first days of the patient's admission at the hospital. In numerous studies, the authors claim that the results of early surgical excision and skin grafting are better than those with delayed operations, but the data on mortality are ambiguous. The authors point out that high mortality is attributed to the elderly age of patients, a larger area of deep burns and the presence of inhalation injury. At the same time, none of the developed prognostic indices that include the above mentioned predictors of a fatal outcome of burn injury have been used for planning a surgical intervention.

Keywords: burns, surgical treatment, wound excision, grafting

Conflict of interests Authors declare no conflict of interest

Financing The study was performed without external funding

For citation: Spiridonova TG, Zhirkova EA, Sachkov AV, Rogal ML, Petrikov SS. Problems of surgical treatment of deep burns. *Transplantologiya. The Russian Journal of Transplantation.* 2025;17(1):76–89. (In Russ.). https://doi.org/10.23873/2074-0506-2025-17-1-76-89

Abbreviations

II, inhalation injury
TBSA, total body surface area

Introduction

Publications on burn injury over a period of more than 50 years have covered a wide range of issues on the pathogenesis of thermal injury, infusion therapy, sepsis, immune disorders, hypermetabolism, inhalation injury (II), early and delayed burn wound excision, wound dressings, wound healing, and scar formation [1]. Since the beginning of the 21st century, survival rates after thermal injury have improved, and the rate of wound infections and sepsis has decreased. This is primarily due to the implementation of early surgical treatment of full-thickness

burns into widespread practice, which is considered the gold standard, but its safety and efficacy, as well as the timing of early burn wound excision and grafting are still being discussed [2–5]. The outcomes of surgical treatment are commonly assessed by the parameters that are considered predictors of an unfavorable outcome of a burn injury: the area of the burn, the age of the patient, the II presence [6], as well as taking into account the length of hospital stay, the need for mechanical lung ventilation, the number of complications, and mortality.

A significant number of studies have discussed to wound dressings, since active surgical tactics for the treatment of extensive full-thickness burns involve wound cover after burn wound excision. Growing the cultured epithelial grafts, fibroblasts and keratinocytes requires a lot of time. Today, more than 30 skin substitutes are used (biological, synthetic, and their combinations). An application of biological coatings, including allo- or xenografts, have been limited to some extent. The problem with synthetic coatings is their low bioactivity [3, 7, 8].

Among the problems that have been unresolved with full-thickness skin burns yet, the leading one is the surgical treatment tactics, which is the subject of this review.

The information on the topic was searched for in the open access electronic databases of scientific literature such as PubMed, Scopus, CrossRef. The search of literature publications was undertaken by using the following keywords: burns, burn injury, full-thickness burns, surgical escharotomy, decompressive therapies in burns, early excision and grafting, early tangential excision and grafting, two-hit hypothesis, damage control. The search depth was over 50 years. The criterion for inclusion of sources in the study was the presence of the full text or abstract of an article. Case report items were not considered.

Escharotomy

In some cases, a burn patient requires escharotomy, the dissection of dense necrotic eschar, upon admission to hospital. This surgical intervention is necessary for full-thickness circumferential burns of the limbs, compression of the chest and(or) anterior abdominal wall by a eschar. The achieved decompression allows eliminating limb ischemia, increasing the excursion of respiratory movements, improving venous and lymphatic outflow. Unlike fasciotomy, necrotomy incisions do not affect the deep fascia [9, 10].

Escharotomy is an emergency and relatively risky procedure, and traditional burn trauma surgical training and the number of health care providers with the experience of performing necrotomy or decompression therapy in the United States and Canada are declining. Our study has found a significant shortage of practicing burn surgeons [9]. To optimize the performance of escharotomy in the upper limbs, burn and plastic surgeons in the United States collaborated with artists and anatomists to develop a simulator. A study using the developed model revealed statistically significant differences in escharotomy technique between experienced and inexperienced surgeons [11]. Authors from the UK have developed a comprehensive course of performing escharotomy by using a simulator to improve training in emergency care of deep burns [12].

The main risks and complications of escharotomy include an insufficiently deep dissection of the eschar, which does not achieve the goal of decompression; delayed bleeding requiring a repeated intervention for the purpose of hemostasis; an excessively deep dissection leading to damage to tendons, vascular-nerve bundles, and exposure of joints; wound infection if the rules are not followed.

Burn wound excision and grafting

In the history of combustiology, passive tactics based on the expectation of eschar spontaneous rejection, granulation growth, and epithelialization of the wound have long been popular. O. Cope et al., in treating patients after the Cocoanut Grove fire in Boston, first developed the concept of “expeditious treatment” of full-thickness deep burns using burn wound excision and grafting. Criticizing the methods of using tannic and pyruvic acids or starch paste, the authors gave examples of performing early surgical excision of the eschar and grafting with good results (Young, 1942; Ackman et al., 1944; Saltonstall et al., 1944; McCorkle et al., 1945). In the aforementioned reports, early burn wound excision and grafting were performed in the period from the first hours to seven days after the burn injury, explaining that this period allowed for dressing the wounds and transporting the patient “to a base hospital in England where surgical facilities were available.” By 1947, O. Cope et al. had operated on 52 burn wounds in 38 patients. Burn wound excision operations were performed under "low spinal anesthesia" with novocaine, gas-oxygen-ether, or intravenous pentothal anesthesia. The wounds after excision were covered with split grafts obtained with a dermatome knife, the flaps were sutured with a continuous suture to the edge of the superficially burned skin. Excision often included muscles, tendons, and deep subcutaneous fascia. All patients were given penicillin, either systemically or locally to the wounds. The results, according to the authors, were "surprisingly" successful. In the discussion, they criticized "the passivity of the surgeon that he has been sitting on the sidelines for so many years watching the full-thickness burn wound degenerate into a bacterial quagmire". It was concluded that immediate excision of the eschar and the wound coating prevented infection [13].

Z. Janžeković, a Slovenian plastic surgeon, revived the interest in early excision in 1970. She published a concept for the management of full-thickness burns by early tangential excision of necrotic tissue with immediate grafting using split-thickness skin grafts. And slough excision was recommended to be started after evaluation of the burn wound and stabilization of the patient's condition after 48–72 hours [14]. In the burn unit of Ljubljana (Slovenia), early excision operations in 2409 patients with subsequent immediate grafting were performed as standard procedures already in the last century. However, the results, significantly superior to the classical conservative tactics, showed that early excision within up to 5 days after the burn did not always solve the problem. The results were usually good in young patients with full-thickness burns up to 40% of the total body surface area (TBSA). With burns over 40% TBSA or even in minor burns in elderly patients with chronic diseases, the outcome of early excision was not so optimistic, which, according to the authors, required an individual approach for each individual case [15].

At the end of the last century, many reports appeared comparing the results of treatment with spontaneous sloughing and excision. J.P. Jouglard et al., having analyzed 101 early excision with immediate grafting, came to the conclusion that for burns covering an area of less than 15% of the TBSA, excision can be performed simultaneously within 12 hours. With good rehabilitation, the cosmetic and functional results were satisfactory [16].

In 1982, the results of so-called "early" excision and grafting (14 days after the burn) were compared at the Washington University Burn Center with the results of grafting after spontaneous eschar sloughing. With excision, the hospital length of stay was statistically significantly shorter, sepsis developed less frequently, and antibiotics were used less frequently than with spontaneous eschar sloughing. However, patients

who had undergone excision required more blood transfusions. No differences were found in mortality rates, the number of operations, or material costs. The authors concluded that in young patients with 20–40% TBSA burns, the method of early excision with grafting is more effective than the one with spontaneous eschar sloughing [17].

Authors from the USA and Turkey reported that excision and grafting operations in the first week after burn injury reduced the incidence of septic complications and mortality, decreased the hospital length of stay and the cost of treatment [18–20].

In the latest three decades of the previous century, early excision with one-stage grafting was performed for minor burns in the USA. However, early excision was not generally accepted for deep burns covering more than 30% of the TBSA in adult patients. A comparative study of the results of early excision and spontaneous eschar sloughing in patients aged 17–55 years with burns covering more than 30% of the TBSA showed that mortality among patients aged 17–30 years with non-inhalation injury burns decreased from 45% to 9% with early excision. No differences in mortality were found among patients over 30 years of age or those with II. The mean length of hospital stay for survivors was “less than one day per per cent of TBSA burn in both children and adults" [21].

Many authors have drawn attention to the higher mortality rate in patients with combined trauma (burns and II) than with only burns. Retrospectively assessing the treatment outcomes in elderly patients (70 years and older) in different time periods (spontaneous eschar sloughing with late grafting, and early excision up to 7 days and grafting), American authors found that mortality was 57% in the early excision group, and 41% in the conservative treatment group (statistically insignificant); and made 48% and 27%, respectively, in the analysis, not including the burn patients with II (statistically insignificant, either). Thus, the authors showed that

early excision and grafting in elderly patients have no advantages, while mortality is higher in patients with skin burns and II [22].

Indian authors conducted a retrospective analysis of the treatment results of 100 patients with extensive burns up to 65% TBSA. Early excision was performed from the 2^{nd} to the 7^{th} day after the burn in patients without severe infection (less than 10^5 bacteria per gram of tissue) in one or two stages. The overall mortality rate in traditional and early excision in all age groups, taking into account II, was 43.4%. In the group of patients with early excision and grafting, the mortality rate was10.2% that was lower (compared to 43.4%, with the traditional treatment method), and showed better functional and aesthetic results [23].

A meta-analysis including 6 studies showed that compared with traditional treatment tactics, early excision in patients with non-inhalation injury burns (regardless of age) significantly reduces mortality and hospital stay. The disadvantage of early surgical intervention in all studies was the large volume of blood loss [4].

Authors from Australia, when comparing the results of survivors and deaths among 80 operated patients over 70 years old, found that significant predictors of death in the elderly population were the total burn area, the deep burn area and the presence of II [24].

The nationwide study in the Netherlands included 3,155 adult burn patients, of whom 505 were aged 65 to 85 years or older. The median burn area (3.2–4.0% TBSA) was comparable to that of younger patients. In older patients, the surgical treatment was initiated earlier and perforated skin grafts for grafting, were most commonly used. Mortality increased with age and was highest in the patients over 85 years of age (23.8%) [25].

Indian authors retrospectively compared the treatment outcomes of 58 patients who underwent early excision with grafting (up to 7 days after

the burn injury) and delayed surgeries (more than 7 days). The results showed that early excision and grafting shorten the hospital stay of burn patients and reduce the cost of treatment. The authors noted that it was important to have a dedicated burns department in both public and private hospitals [26].

In developing countries, the use of active surgical tactics for the treatment of full-thickness burns is difficult. Thus, in the Department of Plastic Surgery and Burns in the Sultanate of Oman, early burn surgery (up to 5 days after the injury) was introduced only in 1997. By the end of 2001, 143 patients had been operated on, of whom only 13% had early excision, and 87% had "delayed primary surgery" excision and grafting from the 6th to the 12th day. In delayed primary excision, necrosis was removed on an area of 50% TBSA in children, and 55% of the TBSA in adults. Not a single patient died. Good functional and cosmetic results were obtained. Indications for delayed primary excision were: unstable patient condition, late transfer from another hospital, delayed patient consent for surgery, extensive burns in the absence of well-trained burn surgeons, department overload. Contraindications for delayed primary excision were the signs of sepsis or organ failure. According to the authors, delayed primary excision is an alternative to early excision and grafting reducing the risk of sepsis, mortality and complications, shortening hospital length of stay and the treatment costs [27, 28].

J.R. Gallaher et al. came to similar conclusions after having evaluated the surgical treatment of full-thickness burns in Africa. Of 905 patients (median total burn area 15% of TBSA), only 33% underwent early excision (no later than at 5 days), and 67% underwent delayed excision (after 5 days). Mortality was statistically significantly higher in the group with early excision (25.3% vs. 9.2%). The authors concluded that early excision and grafting were associated with a significant

increase in mortality, while delayed excision with grafting after 5 days after the burn injury increased survival [29].

Not always excision operations are performed with simultaneous grafting. Indian authors conducted a comparative study of treatment outcomes in burn patients who underwent early excision with grafting in the first 5 days after the burn injury or staged excision and grafting at a later date: after 3 weeks or more. With comparable total burn area (29.1±5.6% of TBSA and 24.7±4.9% of TBSA) and deep burns (9.4±2.3% of TBSA and 8.1±1.6% of TBSA), the early excision with grafting reduced the length of hospital stay by more than 2 times. However, with early excision with grafting, blood loss was statistically significantly greater than with delayed tactics, and amounted to 346±17.6 ml and 241±14.7 ml, respectively, and the need for blood transfusion was 1.6 L and 1.1 L, respectively. The authors believe that active surgical tactics are promising [28].

In the overwhelming majority of studies, excision involves tangential (layer-by-layer) excision of tissue within the dermis. Chinese authors analyzed the results of treating patients with extensive full-thickness burns who underwent the first excision operation to the subcutaneous fat (although the authors call it tangential) with autografting on the subcutaneous fat within 7 days after the injury. The mean age of the patients was 32.4±12.8 years, the total burn area was 89.0±6.2% of TBSA, the area of deep burns was 80.4±7.6% of TBSA. In 80.6% of patients, burns were combined with II. The mortality rate was 42%. The mean timing of the first excision was 4.1±0.6 days after the burn injury, and the area of the first excision was 33.8±7.6% of TBSA with a total area of excision making on average 58.4±10.8% of TBSA. Within 14 days after excision, a cryopreserved allograft or xenograft skin was applied on 84.6%, and the mean time and take rate of autologous skin

graft instead of grafted alloskin or xenoskin was 14.6±0.7 days and 89.5±1.4%, respectively. Scalp was the main donor site for autologous skin, especially for microskin grafting. Wound healing time roughly was 67.3±1.9 days post burn, meanwhile, viable subcutaneous tissue was retained. Skin extensibility and sensitivity improved during follow-up. The authors concluded that the surgical treatment of extensive full-thickness burns was appropriate and effective [30].

W. Tang et al. reported on the experience of staged excision and grafting using a unified surgical treatment scheme from the USA in 137 patients with extensive full-thickness burns. The scheme included: performing excision in the area of the extremities using a tourniquet; subcutaneous administration of a physiological solution with adrenaline in the area of the trunk before excision; multiple use of donor sites. The comparison group included 120 patients with extensive full-thickness burns who were operated on simultaneously, without a unified surgical scheme. The groups of patients were comparable and received identical therapy. In patients with a full-thickness burn area of less than 51% of TBSA, the mortality and complication rates did not differ between the groups. In patients with a deep burn area from 51% to 80% of TBSA, the mortality and complication rates were statistically significantly higher in the comparison group. With a full-thickness burn area of more than 80% of TBSA, the mortality and complication rates in patients in the staged excision group were 25.0% each, while in the comparison group they were 25.9% each, which differed statistically insignificantly. The authors concluded that the USA unified surgical scheme can reduce mortality and complication rates in burn patients only with a full-thickness burn area of 51% to 80% of the body surface area [31]. At the same time, other authors from the USA noted in a later study that mortality depends on the area of full-thickness burns. They calculated that with a full-thickness

burn area of 50% TBSA, the predicted probability of a fatal outcome was 100%, which contradicts the data of the previous study [32].

Iranian authors analyzed the results of surgical treatment in patients with burns up to 60% of TBSA. Excision and grafting were performed at 48–72 hours after injury ("ultra-early" in the authors' terminology) or at 7–10 days ("early"). According to the authors, in the "ultra-early" excision group, the grafting outcome was better, the infection rate was lower, the hospital length of stay was shorter, and the mortality rate was lower. The authors concluded that excision and grafting in the first 48–72 hours after extensive burn injury is more effective than that after 7–10 days [33].

American authors suggested that early excision in the first 48 hours after a burn would be more effective in preventing bacterial colonization of the wound and invasive infections than conservative treatment and delayed excision. The study included 20 patients with thermal injury. Early excision was performed in 12 patients, and delayed excision in 8, since the patients were transferred from another institution on the 6th day after injury. In patients operated on early, the bacterial count was less than 10^5 per gram of tissue, neither infection nor graft loss was observed. In patients admitted late, more than 10^5 bacteria per gram of tissue were detected, three developed infection and a graft loss. The burn eschar excision significantly reduced bacterial colonization in all patients. Higher bacterial colonization and higher infection rates were correlated with late excision. The authors concluded that early excision significantly reduces bacterial colonization of the wound and the incidence of infection compared to delayed excision, therefore, early excision should be aimed at in full-thickness burns [2].

Similar results were obtained in a prospective observational microbiological study of excised necrotic tissue, which was conducted in

the Burn Center of Pakistan. There, 120 patients with deep thermal skin burns up to 40% of TBSA were operated on, excision followed by grafting. Half of the patients admitted immediately after the burn injury underwent early excision and grafting (within 4-7 days); in case of late referral, the delayed excision and grafting (within 1–4 weeks after burn injury) were performed. The groups were comparable in age, gender, and burn area. Microbiological examination of excised necrotic tissue revealed microbial growth in only one patient in early excision group and in 35 in delayed excision group. The most frequently isolated microorganisms were the following: *Pseudomonas aeruginosa* (23), *Klebsiella* (4), *Staphylococcus aureus* (3), *methicillin-resistant Staphylococcus aureus* (3), *Candida albicans* (3), *Escherichia coli* (2) and *Proteus* (2). In 4 patients, 2 microorganisms were cultured. It was concluded that early excision with grafting had advantages over the traditional treatment [34].

In the publications of the last century, there were studies of excision performed in the first hours of the patient's admission at the hospital, but that was usually concerned limited burns. At the end of the 20th century, publications appeared on excision operations for extensive burns in a burn shock phase. Thus, from 1991 to 1997, Japanese authors performed excision and grafting in 15 patients with extensive burns within 24 hours after injury. The mean burn area was 48±20% of TBSA. The mean prognostic burn index (PBI = burn index + age) was 94±23 points. Five patients (33%) died, which is fewer than in 11 other burn units in Tokyo (51.4%). Over the next 6 years, the authors continued the tactics of excision and grafting within 24 hours, operating on another 11 patients. The mean age of all 26 patients was 57±22 years, the mean total burn area was 47±20% TBSA, and the mean burn prognostic index was 94±36. A total of 15 patients survived and 11 (43%) died. The authors

concluded that excision and grafting performed within 24 hours of injury reduced mortality and length of hospital stay in patients with extensive burns [35, 36].

An attempt to determine the optimal time for early excision and grafting in extensive burn injury was the goal of a retrospective study by American authors for the period 1994-2000, including 75 patients with a mean total burn area of 49% of TBSA, of which 44% of the body surface area were full-thickness burns. The mean age of the patients was 36 years. Two groups of patients were compared: those operated on in the first 48 hours and those operated on the 3rd-7th day after the injury. No statistically significant difference in mortality or the number of infectious complications in patient groups was obtained. The authors suggested that the timing of excision and grafting is not of fundamental importance if they are performed before 7 days after the injury [37].

The same conclusion was made by Japanese authors. A multicenter retrospective study included 2,362 patients. The authors compared the efficacy of early (0-2 days) and delayed (3-7 days) excision and grafting operations. The study included patients with extensive burns. A total of 626 patients were operated on early and 1,736 were operated on at later stage. The overall mortality rate was 19.6%. The authors did not find a statistically significant difference between the groups of early and delayed surgical intervention in the first week in in-hospital mortality (15.9% and 17.2%, respectively), length of hospital stay (64.2 days and 65.9 days), duration of mechanical ventilation (33.3 days and 37.9 days), or duration of catecholamine use (29.3 days and 33.6 days). The authors concluded that early excision and grafting in the first 2 days have no advantages over delayed ones up to 3–7 days, despite the fact that several guidelines based on small samples recommend early excision and grafting [38].

A different conclusion was made by American authors after studying the treatment results of patients after early excision (up to 48 hours) and those operated on within from 48–120 hours (3–5 days). The patient groups were comparable in terms of demographic characteristics and severity of burn injury. The analysis included 2,270 patients from the national database of Me 37 (23;55) years old with burns over 10% TBSA. The overall mortality rate was 5%. Patients in both groups did not differ in the number of fatal outcomes, however, in the early excision group, the number of complications such as deep vein thrombosis, pulmonary embolism, ventilator-associated pneumonia, catheter-associated urinary tract infection was statistically significantly lower, and the hospital length of stay and the intensive care unit length of stay was statistically significantly shorter. Treatment outcomes in subgroups of patients with burns of at least 20% TBSA (20–29%, 30–39%, 40–89%, and more than 89%) were better with early excision: the hospital and intensive care unit length of stay were shorter, deep vein thrombosis, venous thromboembolism, and catheter-associated urinary tract infection were less common. The authors believed that excision performed as early as up to 48 hours had an advantage with optimal organization of care for burn patients [39].

A large comparative study of the early excision results was conducted by American authors in 2,522 patients stratified into three groups according the excision timing: within 0-3 days, 4-7 days, and 8-14 days after the burn. The patient age ranged from 0 to 90 years old. In the patients who underwent excision on days from 8-14 after the burn injury, the risk of death was higher compared to the patients who underwent excision on days from 0-3 and days from 4-7 days. A significant decrease in the risk of wound infection and sepsis was found after excision performed on days 0-3 after the burn compared to days 4-7. The rates of

blood transfusions were higher with excision on days 0-3 than with excision on days 4-7. No statistically significant differences were found in the incidence of heart failure, wound infection, and sepsis, or in the volume of blood transfusion between the strata of days 0–3 and 8–14, or between the strata of days 4–7 and 8–14. Thus, excision performed between days 0–3 after a burn injury significantly reduced the risk of wound infection and sepsis compared to excision performed at days 4–7 and 8–14 after the burn, and excision performed in the first 7 days reduced the risk of death compared to excision at days 8–14 after the burn [40].

A special role in the assessment of surgical excision and its consequences is given to the control of intraoperative bleeding. The problem of reducing blood loss in burn patients remains unresolved, despite the use of numerous and varied methods of bleeding control. Some authors presented the results of their studies, which showed that when using a NuStat® dressing and a standard dressing, blood loss per 100 cm^2 of the wound surface with NE was 27 g and 31 g, respectively, and 14 g and 15 g at the donor site, respectively, without statistically significant differences [41].

It is known that severe thermal trauma causes a systemic inflammatory response, which manifestations might be enhanced by the “second hit” phenomenon (infection or surgical intervention); and all that leads to multiple organ dysfunction/failure syndrome and patient's death [42, 43].

Safe burn surgery in the setting of unique pathophysiological abnormalities in severely burned patients should take into account the predictors of an unfavorable burn injury outcome, such as total burn area, area of deep and superficial burns, patient age, inhalation injury presence, coagulation parameters, innate and adaptive immunity, cytokine profile, infection. In authors' opinion, the measures of the blood loss control

(tourniquet, local vasoconstriction, and haemostatic agents), correction of intraoperative coagulopathy, blood transfusion restriction would reduce the likelihood of a “second hit” and make excision safer for a patient with a burn injury [44].

Restoration of skin integument is an important final step in the treatment of a patient with a full-thickness burn, but the results of studies are inconsistent. Comparing and evaluating the results of grafting after early and delayed excision on an area of less than 15% of TBSA, authors from Iran noted that successful grafting was more frequent in patients who underwent early excision and grafting compared to those of the delayed grafting group. The hospital length of stay did not differ between the two groups, and the assessments of pruritus and scar status were comparable after 6 months of follow-up [45].

The authors of the Swedish Burn Center came to opposite conclusions. They conducted a retrospective comparative analysis of two surgical strategies: one-stage excision with simultaneous grafting (1997–1998) and staged excision with temporary wound cover with xenografts (2010–2011). The treatment results of 57 patients with burn 15–55% of TBSA were studied. During the first week, 28 patients underwent excision and simultaneous grafting with a meshed autograft, and 29 patients underwent staged excision with xenoplasty (no more than 20% of TBSA at each stage). Patients in the staged excision group were statistically significantly older than patients in the one-stage excision group. The groups included both adults and children aged 0 years and older. The full-thickness burn area was 5.5% (1.0–23.5%) TBSA in the one-stage excision group, and 14.0% (1.0–40.0%) TBSA in the staged excision group, but the difference was not statistically significant. The following results were obtained: the length of hospital stay, the ratio of the length of stay to the TBSA (slightly more than 1.0) and the area of excised necrosis did not

differ statistically significantly between the groups. As the authors assumed, the number of repeated grafts was higher in the group of one-stage excision with immediate grafting, in which autografting was unsuccessful due to insufficient excision of necrotic tissue. Xenoplasty increased the cost of staged excisions. The authors noted that the reliability of the conclusions is limited by the number of cases and the incomparability of the groups, so further studies are needed [46].

Authors from Australia have completely abandoned grafting after early burn eschar excision in patients with extensive full-thickness burns and currently perform skin grafting within 5 weeks after injury. The authors believe, early grafting, iatrogenically increases the skin defect, threatens with microcirculation disorders, leads to frequent skin graft rejection and impaired healing of donor wounds. The use of the biodegradable NovoSorb™ temporary matrix allows for staged plastic surgery after healing of superficial burns, which, in the setting of complex treatment, leads to recovery of patients with extensive burns [47].

A systematic review and meta-analysis of 16 publications by the scientists from the UK, Malaysia, and South Africa showed that the benefits of early excision are obvious in high-income countries, but are not proven in low-income and resource-limited countries. Publications from 1990 to 2017 included data on the timing, type of surgery, and treatment outcomes. It was shown that in all countries, regardless of the income level, in early excision, the hospital stay was shorter, sepsis developed less often. However, mortality in cases of delayed excision was lower than that in early excision. The authors concluded that a prospective study is needed for more accurate conclusions [48].

In 2011, in Europe, the issues of fluid therapy, nutrition and excision strategy were studied through a questionnaire survey of burn center physicians. Burn centers in 17 European countries submitted 38

questionnaires, which were analyzed. Early excision has been the rule for all centers, although only some of them use laser Doppler to determine the depth of burn damage [49].

In 2015, the American Burn Association conducted a study of the surgical tactics of burn surgeons regarding excision and grafting and its impact on treatment outcomes. A survey of 145 surgeons, members of the American Burn Association, showed that most surgeons in the USA use only visual clinical assessment to determine the depth of burn damage. excision surgery is performed by 56% of surgeons within the first 24 hours after the burn, with 73% of them excising necrotic tissue over an area of more than 20% of the body surface at one time (including in the area of grade II burns, according to ICD-10), and preserving viable dermis. The authors believe that standardization of treatment methods is hampered by individual preferences of surgeons, which may affect the success of new technologies. The authors argue that burn surgery continues to be both a science, and also the state of the art, and its optimization requires accurate documentation of treatment methods and outcomes [50].

In 2018, the World Health Organization launched the Global Burn Registry (GBR). An analysis of the initial results from the database showed that at the time of the study there were 4,307 cases of burn injury treated in 28 institutions in 17 countries, of which 32% were in low-income countries and 68% in high-income ones. The mean age of patients was 24.5±0.5 and 24.2±0.4 years old in low- and high-income countries, respectively, and did not differ statistically significantly. In low-income countries, the total burn area was statistically significantly larger than in high-income countries: 30.5±0.7 % TBSA versus 19.8±0.4 % TBSA; there were more flame burns (55.2±1.4% versus 39.0±0.9%), and mortality was higher (31.9±1.3% versus 9.4±0.5%). This initial analysis

will serve as a basis for further evaluation of burn care and improvement of burn treatment in low-income countries [51].

The severity of the patient's condition and his/her readiness for surgical intervention could have been objectively assessed by using prognostic indices, however, by present, none of the prognostic burn indices have been used for planning the surgical treatment of burn patients [44].

In some studies, along with demographic data, an assessment of patients' condition using specialized prognostic indices ABSI [8], PBI [37], RBS [7] is made, which, however, are not taken into account while planning the timing and extent of performing a primary excision. In our recently published paper, we suggested that our revised Frank Prognostic Index (RFI) will allow both stratifying patients regarding the fatal outcome risk, and also become the basis for developing treatment algorithms (routing, timing and extent of primary NE, fluid therapy), which we have not encountered in any of the publications [52].

Conclusion

A review of foreign literature has shown that there are neither uniform standards for the timing of primary excision, nor for its terminology, i.e. "ultra-early", "immediate", early, delayed. In the last century, "early" excision was defined as that performed within from 48 hours to 14 days; nowadays defined as that performed from 0 to 10 days from the moment of injury.

Since the beginning of the 21st century, in European countries, the USA, and Japan, it has become a rule to perform excision on the first day of patient admission at the hospital. More than half of surgeons in the United States follow this rule, with ¾ of them simultaneously removing

necrotic tissue over an area of 20% of TBSA and collecting the donor skin for grafting, which increases the wound defect.

With early excision (up to 7 days after burn injury), bacterial colonization of the wound and the number of infections are significantly lower, less frequent sepsis and lower requirements in antibiotic use, the hospital length if stay is shorter and treatment costs are lower. With excision performed within up to 48 hours, a statistically significantly lower rates were noted for such compliactions as deep vein thrombosis, pulmonary embolism, ventilator-associated pneumonia, catheter-associated urinary tract infections. The disadvantage of early excision is considered to be a greater blood loss and the need for blood transfusion, which would be "a second hit" for the patient, could worsen his/her condition and lead to death, therefore, in the treatment of patients with thermal injury, the Damage Control approach should be introduced.

In developed countries, the results of early excision and grafting are better than those of delayed operations. However, mortality data for early excision are ambiguous (overall 5-43%, up to 57% in the elderly, 48% in those without inhalation injury and require further prospective studies. Mortality among elderly patients is significantly higher than in young and middle-aged patients with a comparable burn area. Mortality is higher in skin burns with inhalation injury than without it.

The efficacy of early excision has not been confirmed in low-income countries that are lacking specialized burn units, proper intensive care at prehospital stage; there is no way to adequately replace blood loss after early excision with grafting; patient's nutritional status is often compromised; the injury is frequently preceded by anemia, chronic diseases; and the supply of necessary wound dressing material is limited or unavailable.

The authors assess the surgical treatment outcomes in patients with full-thickness burns in their publications taking into account different parameters: the burn area, the patient age, the presence of inhalation injury, and these are the main predictors of a burn injury outcome. All of them in one form or another are included in specialized calculated prognostic indices the most well-known of which are FI, Baux, RBS, PBI, ABSI, BOBI and Ryan. Stratifying the outcome of burn injury patients based on the prognostic indices calculated at baseline could be useful for developing algorithms for the surgical treatment of burns. However, the existing prognostic burn injury-related indices have not been used for strategic planning of surgical procedures in burn patients.

In conclusion we should stress that research into the problems of surgical treatment tactics for patients with burn injuries should be continued. Our Revised Frank index (RFI), which includes the main predictors of fatal outcome, can become the basis for developing the surgical treatment tactics for patients with full-thickness burns.

References

1. *Tekhnika sbora i transportirovaniya biomaterialov v mikrobiologicheskie laboratorii: metodicheskie ukazaniya MU 4.2.2039-05.* Moscow; 2005. Available at: https://ohranatruda.ru/upload/iblock/b8a/4293758559.pdf [Accessed September 26, 2024]. (In Russ.).

2. Isenberg HD. (ed.) *Clinical Microbiology. Procedures Handbook.* American Sosiety for Microbiology; 1992.

3. Leibovici-Weissman Y, Anchel N, Nesher E, Leshno M, Shlomai A. Early post-liver transplantation infections and their effect on long-term survival. *Transpl Infect Dis.* 2021;23(4):e13673. PMID: 34153169 https://doi.org/10.1111/tid.13673

4. Heldman MR, Ngo S, Dorschner PB, Helfrich M, Ison MG. Pre- and post-transplant bacterial infections in liver transplant recipients. *Transpl Infect Dis.* 2019;21(5):e13152. PMID: 31355967 https://doi.org/10.1111/tid.13152

5. Lemos GT, Terrabuio DRB, Nunes NN, Song ATW, Oshiro ICV, D'Albuquerque LAC, et al. Pre-transplant multidrug-resistant infections in liver transplant recipients-epidemiology and impact on transplantation outcome. *Clin Transplant.* 2024;38(1):e15173. PMID: 37877950 https://doi.org/10.1111/ctr.15173

6. Liu N, Yang G, Dang Y, Liu X, Chen M, Dai F, et al. Epidemic, risk factors of carbapenem-resistant Klebsiella pneumoniae infection and its effect on the early prognosis of liver transplantation. *Front Cell Infect Microbiol.* 2022;12:976408. PMID: 36275019 https://doi.org/10.3389/fcimb.2022.976408 eCollection 2022

7. Guo L, Peng P, Peng WT, Zhao J, Wan QQ. Klebsiella pneumoniae infections after liver transplantation: drug resistance and distribution of pathogens, risk factors, and influence on outcomes. *World J Hepatol.* 2024;16(4):612–624. PMID: 38689752 https://doi.org/10.4254/wjh.v16.i4.612

8. Osborn MA, Böltner D. When phage, plasmids, and transposons collide: genomic islands, and conjugative- and mobilizable-transposons as a mosaic continuum. *Plasmid.* 2002;48(3):202–212. PMID: 12460536 https://doi.org/10.1016/s0147-619x(02)00117-8

9. Bonomo RA, Burd EM, Conly J, Limbago BM, Poirel L, Segre JA, et al. Carbapenemase-producing organisms: a global scourge. *Clin Infect Dis.* 2018;66(8):1290–1297. PMID: 29165604 https://doi.org/10.1093/cid/cix893

10. Elshamy AA, Aboshanab KM. A review on bacterial resistance to carbapenems: epidemiology, detection and treatment options. *Future*

Sci OA. 2020;6(3):FSO438. PMID: 32140243 https://doi.org/10.2144/fsoa-2019-0098

11. Dai P, Hu D. The making of hypervirulent Klebsiella pneumoniae. *J Clin Lab Anal.* 2022;36(12):e24743. PMID: 36347819 https://doi.org/10.1002/jcla.24743

12. Satlin MJ, Chen L, Gomez-Simmonds A, Marino J, Weston G, Bhowmick T, et al. Impact of a rapid molecular test for Klebsiella pneumoniae carbapene-mase and ceftazidime-avibactam use on outcomes after bacteremia caused by carbapenem-resistant Enterobacterales. *Clin Infect Dis.* 2022;75(12):2066–2075. PMID: 35522019 https://doi.org/10.1093/cid/ciac354

13. Chang D, Sharma L, Dela Cruz CS, Zhang D. Clinical epidemiology, risk factors, and control strategies of Klebsiella pneumoniae infection. *Front Microbiol.* 2021;12:750662. PMID: 34992583 https://doi.org/10.3389/fmicb.2021.750662 eCollection 2021

14. Chen J, Hu Q, Zhou P, Deng S. Ceftazidime-avibactam versus polymyxins in treating patients with carbapenem-resistant Enterobacteriaceae infections: a systematic review and meta-analysis. *Infection.* 2024;52(1):19–28. PMID: 37878197 https://doi.org/10.1007/s15010-023-02108-6

15. Wu X, Long G, Peng W, Wan Q. Drug resistance and risk factors for acquisition of gram-negative bacteria and carbapenem-resistant organisms among liver transplant recipients. *Infect Dis Ther.* 2022;11(4):1461–1477. PMID: 35551638 https://doi.org/10.1007/s40121-022-00649-1

16. Mackow NA, van Duin D. Reviewing novel treatment options for carbape-nem-resistant Enterobacterales. *Expert Review of Anti-Infective Therapy.* 2024;22(1–3):71–85. PMID: 38183224 https://doi.org/10.1080/14787210.2024.2303028

17. Lasko MJ, Nicolau DP. Carbapenem-resistant Enterobacterales: considerations for treatment in the era of new antimicrobials and evolving enzymology. *Curr Infect Dis Rep.* 2020;22(3):6. PMID: 32034524 https://doi.org/10.1007/s11908-020-0716-3

18. Kuzmenkov AY, Trushin IV, Vinogradova AG, Avramenko AA, Sukhorukova MV, Malhotra-Kumar S, et al. AMRmap: an interactive web platform for analysis of antimicrobial resistance surveillance data in Russia. *Front Microbiol.* 2021;12:620002. PMID: 33776956 https://doi.org/10.3389/fmicb.2021.620002 eCollection 2021

19. *European Centre for Disease Prevention and Control. Antimicrobial resistance in the EU/EEA (EARS-Net) – Annual Epidemiological Report for 2022.* Stockholm: ECDC; 2023. Stockholm, 17 November 2023. Available at: https://www.ecdc.europa.eu/en/publications-data/surveillance-antimicrobial-resistance-europe-2022 [Accessed December 26, 2024]

Information about the authors

Tamara G. Spiridonova, Dr. Sci. (Med.), Scientific Consultant, Department of Acute Thermal Injury, N.V. Sklifosovsky Research Institute for Emergency Medicine, https://orcid.org/0000-0001-7070-8512, spiridonovatg@sklif.mos.ru

50%, review of publications on the topic of the article, writing the text

Elena A. Zhirkova, Cand. Sci. (Med.), Researcher, Department of Acute Thermal Injury, N.V. Sklifosovsky Research Institute for Emergency Medicine, https://orcid.org/0000-0002-9862-0229, zhirkovaea@sklif.mos.ru

15%, review of publications on the topic of the article

Alexey V. Sachkov, Cand. Sci. (Med.), Head of the Scientific Department of Acute Thermal Injury, N.V. Sklifosovsky Research Institute for Emergency Medicine, https://orcid.org/0000-0003-3742-6374, sachkovav@sklif.mos.ru

15%, review of publications on the topic of the article

Mikhail L. Rogal, Prof., Dr. Sci. (Med.), Deputy Director for Science, N.V. Sklifosovsky Research Institute for Emergency Medicine, https://orcid.org/0000-0003-1051-7663, rogalml@sklif.mos.ru

10%, scientific editing of the article

Sergey S. Petrikov, Corresponding Member of the Russian Academy of Sciences, Dr. Sci. (Med.), Director of N.V. Sklifosovsky Research Institute for Emergency Medicine; Head of the Department of Anesthesiology, Intensive Care and Emergency Medicine, Russian University of Medicine, https://orcid.org/0000-0003-3292-8789, petrikovss@sklif.mos.ru

10%, scientific editing of the article

The article was received on September 5, 2024;
Approved after reviewing on September 23, 2024;
Accepted for publication on December 25, 2024