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Yulia V. Ivanova[1], Ph.D., Professor of the Department of Surgery No. 1, https://orcid.org/0000-0003-4464-3035

Igor A. Kryvoruchko[1], Doctor of Medical Science, Professor, Head of the Department of Surgery No. 2, https://orcid.org/0000-0002-5525-701X

Viktor M. Cheverda[1], Ph.D., Professor of the Department of Surgery No. 2, https://orcid.org/0000-0003-0095-1095

Dmytro V. Minukhin[1], Ph.D., Assistant Professor of the Department of Surgery No. 1, https://orcid.org/0000-0003-3371-1178

Svetlana Gramatiuk[2, 3], Ph.D., President of the Ukraine Association of Biobank, MSc Biobanking Lecturer, https://orcid.org/0000-0003-4238-7031

Sergii I. Estrin[4], Doctor of Medical Science, Cardiovascular Surgeon, https://orcid.org/0000-0003-3957-5971

Andrii O. Kovalchuk[4], Ph.D., Cardiovascular Surgeon, https://orcid.org/0009-0001-7615-4845

[1]Kharkiv National Medical University, Kharkiv, Ukraine

[2]Institute of Bio-Stem Cell Rehabilitation, Kharkiv, Ukraine

[3]International Biobanking and Education, Medical University of Graz, Graz, Austria

[4]State Institution "V. T. Zaitsev Institute of General and Emergency Surgery of National Academy of Medical Sciences of Ukraine", Kharkiv, Ukraine

Negative Pressure Wound Therapy in the Treatment of Sternal Infection after Cardiac Surgery: a Case Report and Literature Review

Abstract

The aim. To assess the effectiveness of negative pressure wound therapy (NPWT) in the treatment of sternal infection following heart surgery.

Materials and methods. During 2019-2022, six patients aged from 46 to 69 years underwent NPWT for sternal infection which occurred within 2 to 24 weeks after complete median sternotomy. For the purpose of temporary wound closure, standard dressing kits with sorption sponge were used. Negative pressure was created by electric vacuum pump with a constant vacuum mode at a range of -75 to -115 mm Hg and a duration of 4-5 days per session. In all cases determination of serum procalcitonin, bacteriological examination of wound discharge, computed tomography (CT) of the chest were performed in dynamics.

Results. The study revealed that NPWT in all cases promoted wound cleansing, gradual closing of fistulas and non-grooving pockets, termination of inflammatory process, reduction of the wound cavity, thus accelerating complete wound healing. A significant reduction in the level of wound contamination was revealed after the first NPWT session (below the critical level of 10^3 CFU), compared to that before treatment (10^7-10^8 CFU). Normalization of the level of procalcitonin in the blood serum was determined by day 5-7 of NPWT. CT showed the signs of sternum stability and reduction of inflammatory process in surrounding tissues after treatment. Each treatment case required from 2 to 4 sessions. The duration of hospital stay ranged between 25 and 35 days. A treatment case of one of the 6 patients included in the study is described.

Conclusions. NPWT has proven to have positive clinical effect in the local treatment of postoperative sternal infection and can be applied as an ultimate or a transitional option. Methodology of its clinical application needs further elaboration.

Keywords*: complete median sternotomy, infectious complications, postoperative mediastinitis, methods of wound managing, wound healing.*

Introduction. The first median sternotomy as surgical access to the heart and large vessels was described in 1897 by Milton. Julian and associates popularized it in 1957 [1]. Despite the current trend towards the active introduction of minimally invasive technologies into surgical practice, complete median sternotomy remains the main approach in most heart surgery hospitals worldwide. According to the Adult Cardiac Surgery Database of the Society of Thoracic Surgeons (USA), of 217,829 cardiac procedures in 2013, less than 1% of cases of deep sternal wound infection occurred. At the same time, mortality, according to different literature sources, can reach 50% [2]. Treatment costs for patients with sternal infections are 2.8 times greater compared to patients without complications. Lee et al. pointed to an additional cost of $500,000 per each case of treatment for such patients [3, 4].

Infectious wound complications after median sternotomy are collectively referred to in the literature as mediastinitis, although the infection may be limited to superficial tissues and may not necessarily involve the mediastinum (superficial sternal wound infection). Other terms are also used: "sternal dehiscence," "sternal wound infection," "poststernotomy infection," and "sternomediastinitis".

A large number of prospective and retrospective studies have been published to identify risk factors for sternal infection, over 20 predictors have been identified. The most prognostically significant are obesity, prolonged mechanical ventilation, diabetes mellitus, previous cardiac surgery, postoperative blood transfusion, and the use of the internal mammary artery as a bypass conduit [5]. A number of studies point to the predictable nature of a combination of risk factors. The relative risk for sternomediastinitis related to diabetes mellitus combined with obesity is 5.0. Bilateral use of internal breast arteries for coronary bypass surgery in patients with diabetes mellitus also significantly increases the risk of postoperative complications [5]. Sternal risk assessment scales have been developed but they are not widely used in common practice [6].

Available documents describe the mechanisms that explain the appearance of diastasis between the bone fragments of the dissected sternum and the appearance of wound infection. One theory suggests that local ischemic osteomyelitis is a causal factor in wound complications. Against the background of local changes, the wire sutures in the area of the altered bone weaken and this causes instability of the sternum, and then the divergence of the overlying soft tissues, which creates an infection gate. Experimental work on the study of the anatomical features of the internal mammary artery confirms the ischemic genesis of the deterioration of sternum consolidation after mobilization of the mammary conduit [7]. Similar data were obtained in the study of post-operative blood supply to the sternum with microspheres labelled with radionuclides [8]. However, the study by Green et al. (n=24) using intraoperative laser Doppler monitoring to measure sternal blood flow before, during and after mobilization of the internal mammary artery did not show a significant reduction in blood flow after artery harvesting [8, 9].

Another hypothesis is that inadequate sternorrhaphy with or without asymmetrical sternotomy, with a similar development of the pathological process, is assumed to be a causal factor. In this case, a secondary infection of the wound occurs, and the exudation of the wound spreads to the mediastinum and pericardium, implicating them in the inflammatory process [10, 11].

One more triggering mechanism can be the accumulation of blood and serous exudate in the mediastinum which is an excellent nutritive medium for microorganisms. Fluid build-up can be caused by improper drainage of the surgical site or post-cardiotomy exudative pericarditis while the penetration of the infection takes place through a sore on the skin [6, 10].

Several classifications of sternal wound contamination have been proposed. The first was published by Pairolero and Arnold in 1984. The criterion was the term of complication occurrence after operation. The same parameter was used by El Oakley in his 1996 classification. As additional criteria, the author used the presence of risk factors and previous treatment for wound infection. Yet, none of the above classifications describe the existing anatomy of the infection, making it difficult to choose the proper treatment method [12, 13]. In accordance with the criteria of the US Center for Disease Control and Prevention, wound contamination after sternotomy can be divided into 3 types: a) superficial one, limited to the skin and subcutaneous fat; b) one with the infectious process reaching the sternum but not affecting it; c) cavernous/organ contamination, in which there is osteomyelitis of the sternum and/or infection of the mediastinum. The most recent classification proposed Anger et al. in 2015 [14] reposes also on anatomical criteria thus being comprehensive and objective, according to the authors (Table 1).

The generally accepted method for preventing complications of post-sternotomy wounds in heart surgery is a perioperative antibiotic therapy. In most cases of poststernotomy infectious complications, the flora of the wound is

Table 1

Classification of wound contamination by Anger et al.

Type	Tissue injury	Wound localization	
I	Skin and subcutaneous tissue	Partial*	Upper
			Lower
		Complete	
II	Exposed sternum or ribs	Partial	Upper
			Lower
		Complete	
III	Osteoporosis of the sternum or ribs	Partial	Upper
			Lower
		Complete	
IV	Mediastinum exposed	Partial	Upper
			Lower
		Complete	

Note: * - the border separating the upper and the lower regions is the lower edge of the pectoralis major muscle.

represented by different types of *Staphylococcus aureus*. Most pathogens migrate from patients' own nasal flora. 20–30% of the general population are carriers of *Staphylococcus aureus*, which trebles their risk of developing wound complications caused by this pathogen [3]. Measures to prevent sternal infection include exact median sternotomy, avoiding the use of the internal mammary artery as a bypass in high-risk patients, avoiding the use of wax and local hemostatics that interfere with consolidation of the sternum and are "traps" for infection, accurately matching the halves of the sternum, and compliance with sanitary and anti-epidemic rules in the hospital [3, 5].

A unified concept of surgical treatment for sternal infection has not yet been developed. The choice of the optimal treatment method remains in the hands of the clinic and is determined by the accumulated practical experience. Along with the development of heart surgery, the treatment tactics for post-operative sternomediastinitis have improved. The modern arsenal comprises several optional techniques, each of which has its own pros and cons. At the formation stage, the treatment of post-operative sternomediastinitis consisted of surgical debridement followed by resternorrhaphia or wound healing by secondary tension. Managing open wounds often required mechanical ventilation because the chest was unstable. Prolonged bed rest resulted in complications such as pneumonia, thrombosis and thromboembolism, as well as asthenia, causing mortality of 45% [10, 11]. In some cases, management of open wounds has led to a complication as daunting as breaking the right ventricle through the edge of the sternum, often with a fatal result [15].

A new method of treating deep sternal infection proposed by Shumaker et al. in 1963 was a major advance. The method involved constant irrigation of the mediastinum with an antibiotic. A closed wound and a stable sternum are the indisputable advantages of this method; however, some researchers published data on a high level of suppuration relapses and mortality [4, 11, 12]. As a cause for the recurrence of wound infection, the authors cite a decrease in susceptibility of the bacterial flora to antibacterial drugs and devascularization of the chest wall associated with the harvesting of the internal mammary artery for coronary artery bypass grafting (CABG).

An alternative technique for the treatment of sternal wound infection is based on closed drainage of the mediastinum with Redon catheters without continuous irrigation. This method of treatment of post-sternotomy wound complications was adopted from orthopedic practice, in which it proved excellent in the treatment of osteomyelitis of tubular bones. Redon's drainage ensures the outflow of infected wound discharge and thus reduces the residual wound cavity [16]. The successful application of this strategy was first demonstrated in 1989 by Durandy et al. [16] and confirmed by further studies [12, 13, 17]. The main goal of the above described treatments is to close the wound after debridement. This guarantees the immediate postoperative stability of the sternum, creates the prerequisites for patient's quick weaning from a ventilator and activation.

A relatively recent technical innovation in the management of deep sternal wound infection is negative pressure wound treatment (NPWT), or vacuum assisted closure (VAC) therapy, which allows continuous removal of exudate and reduction of edema, also increases tissue perfusion, maintains a moist environment by stimulating granulation growth [18]. In recent years, NPWT has been widely used as a primary strategy to treat sternomediastinitis in cardiothoracic surgery.

A retrospective analysis of the treatment of 192 patients with deep sternal wound infection by Assmann et al. (2011) demonstrated significant reduction in the terms of hospitalization in patients who undergone NPWT compared to those after primary resternorrhaphy or irrigation-aspiration drainage (45.6±18.5 days versus 55.2±23.6 days). However, 39% of cases required secondary resternorrhaphy and 12% required complex flap surgery following NPWT.

In 2005, Fuchs et al. evaluated the effectiveness of NPWT compared to other methods and came to the conclusion that the time needed to achieve sterile result of bacteriological investigation of the wound discharge and the duration of hospitalization decreased. In 2007 Raja and Berg released data on shortening the time between suture removal with surgical debridement and complete wound closure. Petzina et al. in a retrospective analysis (2010) of 118 cases indicated lower mortality in the management of poststernotomy mediastinitis by negative pressure compared to that by providing dressings and debridement (6% vs. 25%) [2, 25].

Another strategy for treating purulent complications after median sternotomy is the primary or delayed closing of the wound with vascular soft tissue flaps [19]. The use of the main pectoral muscle strip was described in 1980. Subsequent studies showed a mortality rate of 5.1-8.1% and a recurrence of sternal infection of 5.1-44%. Other authors insist on the plastics with a strand of the greater omentum, first described by Lee et al., to cover mediastinal defects, or with a reversed musculus rectus abdominis flap [10, 20]. The results of these studies indicate relatively high post-operative survival, although they all carry additional surgical trauma and the risk of further complications. In the literature, there are publications devoted to the closure of chest wall defects with other autologous materials. The authors used musculus tensor fasciae latae, iliac crest, and fibula [13, 17]. The main disadvantage of these methods is the limited volume of tissues, which allows only small defects to be repaired. The plastics with open flaps using microsurgical techniques to apply vascular sutures as a treatment method for this category of patients is currently seldom used.

The use of allografts and xenografts in surgery for large chest wall deformities has been documented in the literature [20]. After implantation, the material is progressively revascularized and reshaped in patients' own tissue. The material is infection-resistant and is also replaced with autologous cells, even in the area affected by radiotherapy. The properties of modern synthetic materials enable them to be used to replace large defects in the sternum and rib cage. Titanium plates, stainless steel mesh, synthetic polymer mesh and polymethylmethacrylate are also used [20, 21]. They can be fastened onto bony structures with screws or rods.

Thus, the literature data indicate that, despite significant progress in the prevention and treatment of postoperative sternal wound complications, this problem is also relevant for modern cardiac surgery. Due to the absence of strict recommendations, the choice of treatment strategy for these complications is the responsibility of the surgeon.

The aim. To assess the effectiveness of NPWT in the treatment of sternal infection following heart surgery.

Materials and methods. In the period from 2019 to 2022, 6 patients underwent treatment at the Department of Surgical Infections of V.T. Zaitsev Institute of General and Emergency Surgery of the National Academy of Medical Sciences of Ukraine due to postoperative sternal infection which occurred after surgical intervention through complete median sternotomy approach. The patients varied in age from 46 to 69 years. Two patients underwent prosthetic valve replacement, and 4 patients underwent CABG (autovenous and/or mammarial). The time of onset of complications varied from 2 to 24 weeks after surgery. According to the classification of Anger et al., the distribution of patients by type of sternomediastinitis was as follows: type I in 3, type II in 1, and type III in 2 patients.

All the patients underwent standard range of diagnostic procedures, including history collection, clinical, biochemical, and coagulation tests, determination of the level of serum procalcitonin in dynamics. In the presence of fistulas with the discharge, they were examined through a tube while assessing the depth, length and direction of the fistular tract. Bacteriological examination of wound discharge prior to surgical treatment was conducted to determine the types of bacteria and their susceptibility to antibacterial medicines. Among the instrumental studies, all the patients underwent a chest radioscopy in two projections, chest X-ray, echocardiography to determine the presence of fluid in the mediastinum and pleural cavities, and computed tomography (CT) of the chest.

For the purpose of temporary wound closure, standard dressing kits for NPWT were used, KCI VAC Granufoam (KCI Manufacturing Unlimited Company, USA) and HEACO dressing kit DK10 (HEACO Medical Technologies, UK). The size and configuration of the sorption sponge were selected depending on the view of the wound defect in such a way that the sponge completely filled not only the sac but also pockets in the subcutaneous tissue. Negative pressure was created with vacuum pump HEACO NP32S (HEACO Medical Technologies, UK). We used a constant vacuum mode with a range of -75 to -115 mm Hg and a duration of 4 to 5 days. The decision to stop the therapy was made on an individual basis after the reduction of the wound area and its cleansing, as well as in the absence of non-grooving pockets. After the termination of NPWT, topical treatment was continued using ointments and powder formulations.

Results. All the patients complained of fistulas with purulent discharge in the area of the postoperative scar, pain in the sternum while walking or during other exercise. Local manifestations of the purulent process were the presence of external fistulas with purulent discharge in the projection of the metal sutures of the sternum, local inflammatory reaction, pain on palpation of the postoperative wound of the sternum, and signs of instability of the sternum. On admission, a soft tissue review of the postoperative wound was performed, the sternum condition was assessed, and the material was collected for microbiological examination. The microbiological characteristics of the wound discharge were as follows: gram-positive microflora (*Staphylococcus aureus, Enterococcus faecalis*) in monoculture was identified in 3 cases, gram-negative microflora (*Acinetobacter baumannii* and *Pseudomonas aeruginosa*) in monoculture was identified in 2 cases; and microbial association (*Staphylococcus aureus* and *Pseudomonas aeruginosa*) in 1 patient. The number of microbes before treatment initiation greatly exceeded the critical level (10^7-10^8 CFU). De-escalation systemic antibiotic therapy was prescribed.

Taking into account the results of the CT scan and the wound review, the sternum condition was evaluated and NPWT was initiated. In all the patients studied, after the first NPWT session, the microbiological control studies showed a reduction in the level of contamination of the wound below the critical level (10^3 CFU). In the dynamics of the studies, normalization of the level of procalcitonin in the blood serum was determined (by day 5-7 of treatment). Treatment required 2-4 sessions of NPWT. Patients with post-operative sternomediastinitis spent between 25 and 35 days in the hospital. In one patient, the evolution of the disease was complicated by the development of osteoarthritis of the sternoclavicular joint.

Clinical case. Patient S., a 62-year-old man, was admited to the clinic with complaints of pain in the upper 1/3 of the sternotomy scar, the presence of fistulas in the upper and middle 1/3 with a moderate amount of turbid discharge. Thirty days before admission, he underwent aortocoronary and mammary coronary bypass grafting. When examining the patient, instability of the sternum was revealed in the upper 1/3. Through an instrumental revision, a fistulous tract deep down to the sternum in the upper 1/3 of the scar, as well as fistulous tract extended upward along the sternum for 5 cm in the middle 1/3 of the scar were detected, no connections between these two tracts were revealed. According to CT, in the condition after CABG the contours of the sternum edges were fuzzy, with the presence of marginal foci of destruction; gas bubbles were determined between the fragments of the sternum and also in the parasternal soft tissues; the fatty tissue of the mediastinum was compacted, the pericardium in the anterior sections was thickened and the mediastinal lymph nodes were not enlarged (Fig. 1A, 1B). According to the microbiological study, methicillin-resistant *Staphylococcus aureus* (MRSA) x 10^7 CFU was identified. A decision was made to install a "double" VAC system (Fig. 2). Its parameters were as follows: vacuum level from -75 to -115 mm Hg, mode: constant, change of sorption sponges: once every 4 days. NPWT was discontinued on day 8. The level of microbial contamination after the first session was found to be below the critical value (< 10^3 CFU) (Fig. 3A), and after the second session decontamination of the wounds was achieved.

As the control CT study has shown, foci of the destruction of the sternum edges remained, the rest of the sternum contours were clearer, gas bubbles were not detected, infiltrative changes in the subcutaneous tissue and mediastinal tissue were not detected, yet the pericardium was still thickened in the anterior sections.

The wounds healed by secondary tension 14 days after the start of NPWT (Fig. 3B).

Discussion. NPWT became widespread in the 20th century and is now widely used to treat large, chronic wounds and necrotizing fasciitis worldwide. The theoretical substantiation, elaboration of modern approaches to vacuum wound treatment and the actual formation of the whole field of NPWT belong to the American scientists Morykwas and Argenta (1997).

In 2019, Kim et al. formulated and published new recommendations for the use of NPWT [22]. Despite many years of experience in the use of vacuum therapy in clinical practice, there is still no single generally accepted terminology, that indirectly indicates the continuing contradictions in the concept of the essence of the method [23], while clinical publications on the use of NPWT in sternal infection are very limited.

The mechanism of influence of NPWT in patients with complications after sternotomy is similar to its influence when used for the treatment of soft tissue defects. Among the main efficiency factors of NPWT are macro-deformation, micro-deformation, changes in perfusion, control of

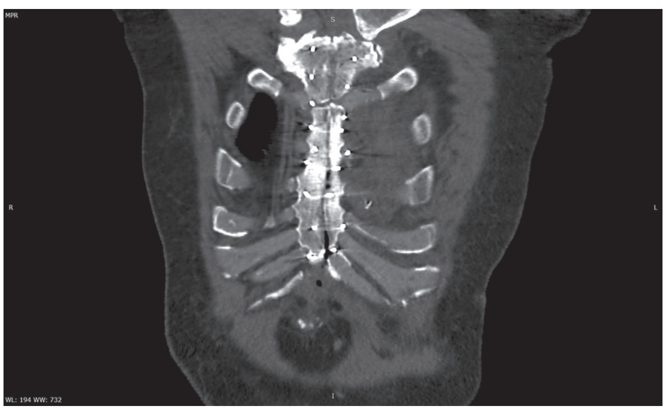
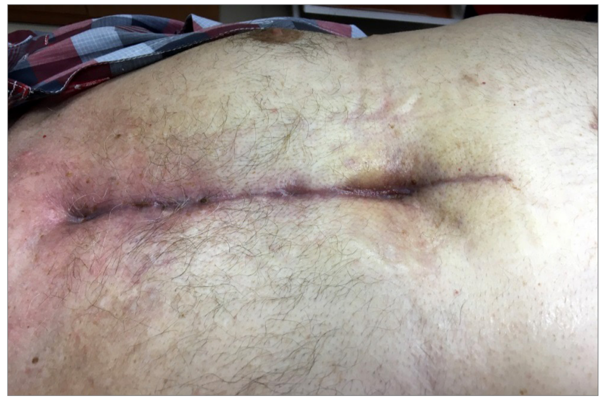


Fig. 1A. *Frontal CT scan of the sternum*

Fig. 1B. *Sagittal CT scan of the sternum*

Fig. 2. *Installation of a "double" VAC system*

A



B

Fig. 3. *Views of the wound at the stages of treatment: A, on the 8th day; B, on the 14th day of the treatment*

exudation, and bacterial decontamination [24]. Macro-deformation is generally understood as the impact of the negative pressure on the wound edges, which converge under its effect. Apparently, in the case of sternomediastinitis, a decrease in the area of the wound contributes to a convergence of the sternum edges and a decrease in its defect.

Microdeformation is understood as microscopic changes in the cytoskeleton of tissues that are affected by the negative pressure. As a result of these changes, signaling systems are triggered leading to the release of growth factors that regulate cell proliferation and migration, an increase in the expression of extracellular matrix components and constriction elements necessary for healing.

The use of NPWT leads to temporary hypoperfusion at the edges of the defect, resulting in an increase in the local concentration of hypoxia-induced factor 1α and vascular endothelial growth factor, which enhances neoangiogenesis. In addition, increased local blood flow helps to improve the supply of oxygen and nutrients to tissues in the defect area, while simultaneously removing waste products.

Reducing tissue exudation improves healing by reducing the severity of interstitial edema, which contributes to the development of chronic defects due to the local compression of cells and tissues. Despite the fact that the mechanism of influence of the removal of excess fluid from the extracellular space has not been completely studied, it is believed that the positive effect of NPWT is associated with a decrease in compression by excess fluid of the microvascular bed and, accordingly, an improvement in blood flow in it. A decrease in the bacterial charge of the wound is also associated with its accelerated healing thus being a rather important factor in its final closure.

To summarize, NPWT in the treatment of deep sternal infection after cardiosurgical interventions can reduce the duration of treatment and can be used as a transitional or, in some cases, the ultimate method for the treatment of infectious complications after sternotomy [22, 23, 25].

Conclusions

1. NPWT has proven to have a positive clinical effect in promoting the healing of poststernotomic infected wounds.
2. In most cases of deep sternal infection, NPWT should be considered as a primary option due to its availability and non-traumatic approach.
3. Methodology of clinical application of NPWT, as an ultimate or a transitional method for deep sternal infection, needs further elaboration.
4. As the innovation in the complex treatment of postoperative sternal infection with big tissue defects, it may be worth considering the additional use of tissue engineering and cell therapy methods along with NPWT.

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Informed consent statement

Not applicable.

Compliance with ethical standards

The work has been approved by the Ethics Committee of Kharkiv National Medical University, Ukraine (Protocol No. 6, November 11, 2022). The number of state registration is 0116u00499.

Conflicts of interest

All the authors declare no conflicts of interest.

Informed consent process

Informed consent was obtained from all participants included in the study.

Data availability statement

All data associated with this study are present in the paper.

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Терапія ран із застосуванням негативного тиску в лікуванні стернальної інфекції після кардіохірургічних втручань: клінічне спостереження та огляд літератури

Іванова Ю. В.[1], Ph.D., професор кафедри хірургії № 1
Криворучко І. А.[1], д-р мед. наук, професор, завідувач кафедри хірургії № 2
Чеверда В. М.[1], Ph.D., професор кафедри хірургії № 2
Мінухін Д. В.[1], Ph.D., доцент кафедри хірургії № 1
Граматюк С.[2, 3], Ph.D., президент Української асоціації біобанку, викладач з біобанкінгу
Естрін С. І.[4], д-р мед. наук, серцево-судинний хірург
Ковальчук А. О.[4], Ph.D., серцево-судинний хірург

[1]Харківський національний медичний університет, м. Харків, Україна
[2]Інститут відновлення біостовбурових клітин, м. Харків, Україна
[3]Міжнародний біобанкінг та освіта, Медичний університет Грацу, м. Грац, Австрія
[4]Інститут загальної та невідкладної хірургії імені В. Т. Зайцева НАМН України, м. Харків, Україна

Резюме

Мета – оцінити ефективність методу терапії ран низьким тиском (ТРНТ) у пацієнтів із стернальною інфекцією після кардіохірургічних втручань.

Матеріали та методи. За період 2019–2022 рр. з приводу післяопераційної стернальної інфекції, яка розвинулася в строки 2–24 тижні після повної серединної стернотомії, проходили лікування 6 пацієнтів віком 46–69 років. У всіх досліджуваних відзначались характерні місцеві та загальноклінічні прояви запального гнійного процесу післястернотомної рани, які вважали показаннями для початку ТРНТ. Усім хворим виконували діагностичні заходи в динаміці, включно із визначенням рівня прокальцитоніну сироватки крові, бактеріологічним дослідженням виділень з рани, комп'ютерною томографією грудної клітки. При проведенні ТРНТ для закриття ранової порожнини використано стандартні перев'язувальні набори із сорбційною губкою. Для створення негативного тиску до перев'язувальних наборів підключали електричні вакуумні апарати, які працювали в постійному режимі розрідження в діапазоні –75...–115 мм рт. ст. Тривалість кожного сеансу до зміни губки становила 4–5 діб. Критеріями припинення ТРНТ були: зменшення площі рани, її очищення, зникнення сліпих кишень і норицевих ходів.

Результати. У всіх пацієнтів ТРНТ сприяла повному загоєнню інфікованої післястернотомної рани шляхом очищення її порожнини, поступової ліквідації сліпих кишень і норицевих ходів, зменшення ранового дефекту, купірування запального гнійного процесу в грудині і прилеглих м'яких тканинах. Якщо мікробне число до початку лікування у всіх випадках суттєво перебільшувало критичний рівень (10^7–10^8 КОЕ), то після першого сеансу ТРНТ відзначено зниження рівня контамінації ран нижче критичного рівня (10^3 КОЕ). При дослідженні сироватки крові на прокальцитонін відзначено нормалізацію його значень на 5–7-у добу від початку ТРНТ. Комп'ютерна томографія в динаміці виявила ознаки покращення консолідації країв грудини, зменшення вираженості остеоміеліту та запалення прилеглих м'яких тканин. У процесі лікування знадобилося від 2 до 4 сеансів ТРНТ. Після припинення ТРНТ продовжувалося місцеве лікування залишкових ранових дефектів мазевими і порошковими засобами до повного загоєння вторинним натягом. Строки перебування хворих у стаціонарі становили від 25 до 35 діб. Наведено клінічний випадок лікування одного з 6 пацієнтів, залучених у дослідження.

Висновки. ТРНТ має клінічно та лабораторно доведений позитивний ефект у місцевому лікуванні післяопераційної стернальної інфекції. Становлячи технічно доступну та малотравматичну альтернативу рестернорафії, ТРНТ може розглядатись як незамінний перехідний або остаточний метод місцевої терапії цього ускладнення. Методологія застосування ТРНТ, ізольовано або в комплексі з іншими методами, потребує подальшого уточнення.

***Ключові слова**: повна серединна стернотомія, інфекційні ускладнення, післяопераційний медіастиніт, методи лікування ран, загоєння ран.*

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