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MECHANISMS OF ACTION OF VACUUM WOUND THERAPY

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Action mechanisms of negative pressure wound treatment

Summary: The article describes in detail action mechanisms of negative pressure wound treatment (NPWT) – one of the latest techniques used in various etiologies wound treatment. Negative pressure provides continuous evacuation of fluid, stimulates the proliferation of granulation tissue and effectively cleans the wound surface. Local prolonged negative pressure wound treatment is currently carefully developed, reliable, efficient and professional wound treatment technology. NPWT can significantly reduce time and cost of treatment.
Keywords: wound treatment, vacuum therapy, negative pressure wound treatment, vacuum assisted closure.

Surgery, as one of the fundamental disciplines of medicine, is closely related to such concepts as "wound" and "wound process." The problem of treating acute and chronic wounds remains relevant [1-3]. According to the World Health Organization, one-third of surgical patients experience purulent diseases. In the presence of a variety of factors that disrupt the development and completion of the wound healing process, infection remains the most common and dangerous complication due to its unpredictability. Approximately 40% of surgical patients experience purulent-inflammatory wound complications that require prolonged treatment, especially if they become chronic. In economically developed countries, the average duration of treatment for one patient with an open severe fracture complicated by osteomyelitis is 158 days, the total period of disability is about 2 years, and the total cost of treatment is 200,000–250,000 dollars [6, 7]. In addition, the incidence of antibiotic-resistant microflora is increasing [5]. The formation of biofilms on the surface of wounds, it creates difficulties with the general and local application of antibacterial agents [5, 14].
The search for effective methods of wound treatment that prevent and/or neutralize pathogens is ongoing; new medical technologies and equipment are being introduced into clinical practice.Chasnoit A.Ch.1, Zhilinsky E.V.1, Serebryakov A.E.1, Leshchenko V.T.21Belarusian Medical Academy of Postgraduate Education, Minsk2City Clinical Hospital of Emergency Medical Care, Minsk, Belarus
In the last decade, there has been widespread interest in the treatment of acute and chronic wounds with negative pressure (NPWT) [3, 4, 11, 12]. This method is based on the use of a closed drainage system that maintains controlled negative pressure in the wound area. As a result, favorable conditions for the wound healing process are created in the damaged area, facilitating rapid cleansing of the wound bed, the maturation of "healthy" granulations, and their subsequent closure with local tissues, skin flaps, or grafts [7]. According to a number of authors, vacuum

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therapy improves the progression of all stages of the wound healing process by reducing local edema and increasing local blood flow [4, 13]. The combination of vacuum therapy with antiseptics helps reduce the level of microbial contamination of wounds and reduces the size of the affected area [10, 13]. This technology reduces exudation in the wound area and maintains a moist environment, which is essential for successful healing of soft tissue defects. Vacuum therapy has been introduced into clinical practice in most surgical specialties. The medical literature describes examples of the successful use of negative pressure in the treatment of venous leg ulcers, diabetic foot ulcers, infected wounds, pressure ulcers, burns, and postoperative wounds [3, 6, 8, 10, 14].

The WaterLily vacuum wound therapy system, manufactured by Eurosets (Italy), is registered in the Republic of Belarus. This system uses a soft polyurethane foam sponge with a pore size of 400–2000 μm or a gauze dressing as a drainage material. Other mandatory components of the system include an adhesive film covering, a non-collapsible drainage tube of sufficient length, and a vacuum source equipped with a container for collecting fluid [4].

The literature describes the following mechanisms and effects of localized negative pressure on a wound.

1. Active removal of excess wound discharge, including biologically active substances that slow wound healing.

NPWT ensures continuous fluid removal from the wound. Chronic effusion can weaken the healing wound because the exudate contains elevated levels of inflammatory mediators and proteolytic enzymes. When wounds fail to heal for a long time and become chronic, the wound fluid is at the mercy of high levels of oxidative enzymes, cytokines, leukocytes, and proteases, which impede the healing process. Chronic inflammation is associated with a vicious cycle in which inflammatory cells produce cytokines, which in turn attract even more neutrophils, macrophages, and lymphocytes. Several studies have shown that at the molecular level, this is associated with an imbalance between the concentration of proteases (MMP-3, MMP-9), protease inhibitors (TIMP-1), and proinflammatory cytokines (tumor necrosis factor (TNF), interleukin-1-beta) [9, 19].

A study by Scherer et al. showed that pro-MMP levels decreased immediately after NPWT and during a 10-day follow-up period [4]. A recent study involving 8 adult patients receiving NPWT for chronic lower extremity ulcers showed that TNF levels in wound exudate decreased significantly within the first 24 hours of treatment, and this decrease continued for 7 days of therapy [4]. Moreover, the amount of exudate removed gradually increased with increasing negative pressure (Fig. 1).

Maximum wound fluid removal was observed at a pressure of approximately -125 mmHg, with half the amount of exudate removed at approximately -25 mmHg. Thus, for wounds with a large volume of effusion, high negative pressure (-125 mmHg) is necessary at the initial stage of treatment. For heavily exuding wounds over a large area, the need for a higher level of negative pressure will likely be temporary (for one or two days), after which the pressure can be reduced to a level more suitable for wound healing.

S. Lindstedt et al. showed that vacuum therapy for extensive abdominal wounds for 6 minutes at a pressure of -70 mmHg allowed for maximum removal of wound fluid—up to 500 ml [4]. However, according to studies conducted on small wounds, most of the fluid (approximately 60 cm3) is evacuated from the wounds within the first 3 minutes after applying NPWT (Fig. 2).These examples demonstrate that the number of reasons for using negative pressure below –75 mmHg is limited.

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2. Maintaining and maintaining a moist wound environment that enhances angiogenesis and fibrinolysis, promotes the normal functioning of growth factors and stimulates marginal epithelialization.

Moisture balance is important in all phases of the wound healing process [1–4]. A moist wound environment accelerates epithelialization, increases the effectiveness of growth factors, enhances the proliferation of keratinocytes and fibroblasts, increases collagen synthesis, and promotes angiogenesis and wound contraction. A decrease in moisture can cause cell death, while excess moisture will lead to maceration of the wound edges and adjacent healthy skin. Therefore, during treatment, it is necessary to establish a balance and avoid extremes that can delay regeneration processes [4].

3. Acceleration of bacterial decontamination of wound tissue.

The presence of necrotic tissue in the absence of adequate wound drainage creates favorable conditions for the growth of microorganisms and high levels of contamination of the wound surface. This has been confirmed by both domestic and international authors (Svetukhin A.M., Zemlyanoy A.B. et al., 2003; Lipsky B.A., 2005) [4]. Active aspiration during vacuum wound therapy creates a flow of fluid directed from the tissues, which facilitates the elimination of microbial bodies and toxins and prevents microorganism penetration into deeper tissues. The use of NPWT accelerates wound decontamination by 2 times and reduces the incidence of patients with high microbial counts in wounds by 2.5 times (Kovalev A.V., 2010). Thus, studies by A. DeFranzo et al. and M. Morykwas et al. have shown that a reduction in microbial contamination below a critical level with vacuum therapy is achieved by the 4th–5th day, while with other methods of local wound treatment, it is achieved only by the 11th day [17].

4. Increased local blood circulation in the wound and a decrease in local interstitial tissue edema.

Vacuum therapy improves the course of all stages of wound healing by reducing local edema and increasing local blood flow [4, 13, 16]. M. Morykwas et al. were the first to describe changes in local blood flow during NPWT [11, 12]. In their rather limited study, blood flow was measured using laser Doppler ultrasound in an experimental pig model: it was shown that the increase in tissue perfusion reaches its maximum at a pressure of –125 mmHg [4, 11]. Moreover, the increase in local blood flow intensity at a pressure of –125 mmHg reached approximately 400% compared to the baseline level. Based on the results of this study, a pressure of -125 mmHg became the recommended value for clinical use of vacuum therapy.

5. Wound base deformation.

The microdeformation effect induced by NPWT, i.e., the microscopic interaction between the artificial filler in the wound and the newly formed granulation tissue, was morphologically studied. The results of these studies showed that the use of sponge and gauze as wound fillers causes microdeformation of the wound base [4] (Fig. 3).

It is believed that the walls of the open pores of the sponge adhere to the granulation tissue, while the interior of the pores does not contact the wound. Thus, due to localized negative pressure, tissue stretching and deformation occur. The resulting change in the shape of the cells of the evacuated tissue stimulates their migration and proliferation [4, 16]. M.L. Venturi et al. showed that intermittent negative pressure was more effective than continuous pressure in stimulating wound healing, since intermittent NPWT causes greater cell deformation [18]. The use of a sponge as a contact layer (with or without vacuum therapy) plays a significant role in activating angiogenesis processes, and the combined use sponge and NPWT induce active cell proliferation [4, 15, 18].

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6. Wound reduction.

One of the fundamental effects of NPWT is macrodeformation of the wound edges [4, 19]. Direct negative pressure on the wound bed and edges under external insulation produces a constant contraction effect on the wound edges, promoting its contraction. This effect directly reduces the wound size, regardless of the intensity of cell proliferation [6]. It is believed that this mechanical effect occurs due to the appearance of transverse forces on the contact surface of the wound and dressing, initiating a cascade of processes that ultimately lead to the formation of granulation tissue and wound healing [9]. It has been shown that the degree of macrodeformation, i.e., the reduction in wound area, gradually increases with increasing negative pressure, reaching half the maximum effect at -45 mmHg and almost the maximum at -75 mmHg [15]. Some researchers note that the type of wound filling used in NPWT affects the degree of wound contraction, with sponges producing greater wound contraction than gauze. This is believed to be due to the open-cell structure of the sponge [4, 10]. Other authors believe that the degree of wound contraction is independent of the material (sponge or gauze) used as the wound filling (Fig. 4).

7. Wound hypoxia.

Measurements using invasive laser Doppler have shown that NPWT reduces blood flow at a distance of 0.5 cm from the wound edge. The mechanism of this effect has been described [4, 8]. For example, N. Kairinos et al. [8] demonstrated that increasing the level of negative pressure during NPWT promotes a gradual increase in pressure on the wound edge tissue, causing hypoperfusion in the treated area (Fig. 5).

NPWT-induced wound hypoxia has advantages and disadvantages. On the one hand, the direct application of vacuum to the wound leads to a localized decrease in the partial pressure of oxygen in the wound, which stimulates the formation of new vessels and an increase in the volume of granulation tissue [4, 15, 17, 19]. On the other hand, impaired blood flow in tissues with already depleted blood supply (e.g., in diabetic foot syndrome, after free thin-thickness autologous skin grafts) can lead to the development of ischemia [4]. Therefore, when choosing the pressure level for NPWT, it is necessary to consider the type of wound and its degree of vascularization [4, 11].

8. Prevention of hospital-acquired infections.

The use of vacuum dressings isolates the wound from the external environment and significantly reduces the likelihood of secondary wound infection, which occurs primarily due to hospital-acquired antibiotic-resistant microflora. Furthermore, raining wound fluid into isolated reservoirs prevents contact with infected, potentially hazardous dressing materials of other patients and medical personnel. Nala. A prolonged absence of dressings in a hospital patient (and therefore wound contact with instruments and air at a medical facility, and with the hands of medical personnel) reduces the risk of wound surface contamination with hospital-acquired strains of microorganisms [17].

9. Enhanced effectiveness of drug therapy.

Enhanced local blood and lymph circulation and transcapillary transport improves perfusion of the wound bed and increases the concentration of systemically administered medications in the wound tissue. This ultimately increases the overall effectiveness of treatment.

10. Reducing treatment costs. Improving quality of life.

In today's economic climate, the tenth positive effect of vacuum therapy is the reduction in treatment costs. Vacuum dressings are applied continuously for a long period (even during the initial phase of wound healing), which allows for savings on dressings, topical medications, and the time and energy of medical personnel – thus reducing the cost of wound treatment [4, 10, 12–14].

The elimination of the need for frequent dressing changes eliminates the inevitable pain associated with them; as a rule, the length of hospital stay and overall treatment are reduced – all of this reduces financial costs and (most importantly) improves the quality of life for both patients and their families.

Thus, local prolonged negative pressure wound therapy is currently a well-developed, reliable, effective, and professional technology for treating wounds of various etiologies. Further implementation of NPWT will improve treatment outcomes not only for burns and chronic wounds, but also for extensive traumatic or purulent tissue lesions, significantly reducing treatment time and costs.

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