https://doi.org/10.15360/1813-9779-2022-2-83-89

Conservative Therapy of Pressure Ulcers Using Physical Methods (Review)

Elkhan G. Osmanov[1], Aleksandr M. Shulutko[1], Aleksey A. Yakovlev[2], Aleksej Y. Krylov[1], Aleksandra V. Yakovleva[2]*, Evgeny L. Altuкhov[2], Elena G. Gandybina[1], Ivan A. Martynov[1]

[1] I. M. Sechenov First Moscow State Medical University, Ministry of Health of Russia, 8 Trubetskaya Str., Bldg. 2, 119991 Moscow, Russia
[2] Federal Research and Clinical Center of Intensive Care Medicine and Rehabilitology, 25 Petrovka Str., Bldg. 2, 107031 Moscow, Russia

For citation: *Elkhan G. Osmanov, Aleksandr M. Shulutko, Aleksey A. Yakovlev, Aleksej Y. Krylov, Aleksandra V. Yakovleva, Elena G. Gandybina, Ivan A. Martynov. Conservative Therapy of Pressure Ulcers Using Physical Methods (Review). Obshchaya Reanimatologiya = General Reanimatology.* 2022; 18(2): 83-89. http://doi.org/10.15360/1813-9779-2022-2-83-89 [In Russ. and Engl.]

Summary

In Russia and European countries, the incidence of pressure (decubitus) ulcers in sedentary patients with severe comorbidities, spinal trauma, and cerebral accident sequelae varies from 3 to 40%, reaching 80% in the chronic critical illness. The final result of conservative treatment of pressure ulcers (PU) with adequate correction of comorbidities and proper care of the immobilized patient depends largely on the choice of local interventions.

Aim of the review: to demonstrate the range of effective methods of physical treatment of pressure ulcers suitable for conservative treatment.

Materials and methods. We selected and analyzed 80 scientific publications. Sources were selected from the PubMed, Scopus, and RSCI databases of medical and biological publications. The following methods were covered: negative pressure wound therapy, ultrasonic methods, hydrosurgical treatment, plasma flows, laser therapy (including low-level laser therapy), «hardware» acceleration of regenerative processes, including electrical stimulation, as well as a combination of these methods.

Results. The variety of physical methods of wound treatment, on the one hand, provides an opportunity to select an individual therapy program. On the other hand, each method has its own limitations and contraindications. That is why in practice various combinations of these methods are reasonable.

Conclusion. For several objective reasons, no reduction of PU incidence in clinical practice is expected. Therefore, studying the issues of evidence-based clinical effectiveness and economic feasibility of various conservative techniques of decubitus treatment to find best solutions in this area is warranted.

Keywords: pressure ulcer; bedsore; surgical technology; physical treatment

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

Full text of the article in Eng. read on www.reanimatology.com

Introduction

Bedsores, or decubitus ulcers (DU), are one of the major health care problems worldwide. They affect patients with severe comorbidities, spinal trauma, and cerebral accidents. In Russia and European countries, the incidence of DU in sedentary patients with the above-mentioned comorbidities varies from 3 to 40%, reaching 80% in chronic critical illness due to severe brain damage [1–5].

In immobilized patients, it is extremely difficult to completely avoid factors contributing to DUs (e. g., constant high pressure on the skin and soft tissues, friction and body movements, moist skin), which complicates their treatment [1, 6–9]. In addition, the severity of the underlying disease entails depletion of plastic reserves of the patient's body, which is usually followed by anemia, pneumonia, and protein-energy deficiency [10–13]. All the above mentioned conditions dramatically slow down the wound healing, sometimes for many months, and due to heterogeneity of macroscopic changes one can simultaneously observe areas of necrosis and granulation tissue [14, 15].

When radical surgical correction of DU is not feasible, prolonged conservative therapy is the only treatment option [16, 17]. Comprehensive approach including conservative measures aimed at stabilizing the patient's status, eliminating the source of external pressure, correct positioning in bed, and active surgical ones, such as debridement and drainage of the infection focus [8, 17–24], should be employed [8, 17–24]. The use of new physical treatment methods, up-to-date wound dressings, and pharmacological formulations to create optimal

Correspondence to:

Alexandra V. Yakovleva
E-mail: avyakovleva@fnkcrr.ru

Адрес для корреспонденции:

Александра Витальевна Яковлева
E-mail: avyakovleva@fnkcrr.ru

conditions for the healing of the wound defect are crucial in this situation [17, 25–38]. Undoubtedly, the success of conservative therapy directly depends on the size of the decubitus ulcer; however, some authors have reported cases of successful treatment of stage III–IV DU during 4–6 weeks with the appropriate addition of methods stimulating tissue repair [17, 24, 39, 40].

The aim of the review is to show the range of effective physical treatment methods for decubitus ulcers suitable for conservative treatment.

To evaluate the physical methods, we searched the English-language PubMed and Scopus databases of medical and biological papers, as well as the Russian RSCI bibliographic system for publications dated within the last 20 years.

General description of physical treatment methods

A separate vast area in conservative therapy of chronic non-healing wounds, including DUs, involves topical treatment with physical and chemical agents. In this case, a particular method can be used not only alone, but also as a part of an integrated treatment, ensuring adequate forced necrolysis (cleaning decubitus ulcers from fibrin, pus and dead tissues), stimulating regeneration and wound epithelialization [4, 14, 17, 41].

Physical factors of mechanical and wave energy. Vacuum therapy of wounds based on negative pressure generation in the DU area is currently widely available [42–45]. Its therapeutic effect is achieved not only by forced cleaning of the lesion from bacteria and necrotized tissues, but also due to normalization of pH of the wound environment, enhancement of microcirculation in the wound area and lymph flow, control of edema and exudation. There are also biological effects such as stimulation of granulation tissue, microdeformation and reduction of inflammation [46]. This method is effective as a part of an integrated treatment of purulent and necrotic soft tissue lesions, including DU, fistulas, trophic ulcers, peritonitis. In addition, vacuum therapy is successfully used in highly contaminated DUs (e. g., as a result of fecal contamination) [47]. Advances in technology and development of portable negative pressure generators have promoted this technology [25, 26, 45]. Recently, researchers suggested using vacuum therapy with fluid (such as normal saline) instillation (NPWTi-d) to increase the efficiency of the procedure [48, 49]. Such a combination improves wound cleansing and accelerates granulation tissue formation.

The use of ultrasound is one of the well-established methods. The therapeutic efficacy of this technique is based on the destructive effect of oscillating waves without a significant increase in tissue temperature [50]. Two ultrasound treatment types used in DU therapy include ultrasonic blade debridement and ultrasonic cavitation [50]. The latter causes destruction of non-viable tissues containing much fluid or calcifications due to formation of microbubbles in liquid medium under the effect of high amplitude ultrasound wave [28, 51]. Meanwhile, «selective destruction» is performed, because healthy tissues contain a large number of elastic elements such as vessels and ducts which are less responsive to the ultrasonic wave. In addition, metabolic shifts generated during ultrasonic cavitation trigger a wide range of photochemical reactions, which, for example, cause mast cell degranulation, increased prostaglandin activity, disintegration of bacterial cell membranes [50]. The bactericidal effect of ultrasonic cavitation can be enhanced by using an antiseptic solution acting as an acoustic medium [28, 50]. Moreover, the use of non-contact devices with relatively constant settings can reduce the inflammatory response despite the lack of significant changes in the bacterial load. Ultrasonic devices requiring direct contact with the wound decrease bacterial load by reducing the biofilms [51]. Thus, the physician can choose which component of the infectious inflammation needs more attention at a specific stage of treatment.

Mechanical debridement of pressure ulcers also includes hydrosurgical treatment, which allows to selectively remove bacteria and nonviable tissues from the decubitus avoiding damage to the surrounding viable tissues [52]. A high-speed (up to 1600 km/h) fine-dispersed flow of normal saline is generated in the device under ultra-high pressure. The jet movement is tangential to the wound. Like a scalpel blade, it cuts necrotic tissue, fibrin deposits, preserving surrounding viable tissues [53]. Thus, a clean and smooth surface of the decubitus is quickly formed. This intervention, however, requires general anesthesia.

Physical factors of thermal energy include laser radiation and plasma technology. Over the past 15–20 years, plasma flows (PF) have become widespread in clinical practice. The studies have shown such advantages of the technology as virtually bloodless dissection of necrotic tissue, high quality hemostasis due to high-energy exposure, wound surface sterilization due to «hard» ultraviolet irradiation (λ<250nm), high ozone concentration (>0.5 mg/m^3) in the operating field [54]. More importantly, optimal conditions are created for tissue regeneration primarily due to the stimulating effect of intermediate ionization products and exogenous nitric oxide (II) of the air-plasma jet (NO-therapy). According to A. Shulutko et al. (2018), the use of plasma «scalpel» in 290 patients with purulent necrotic soft tissue lesions reduced the number of surgical debridement sessions by 1.5–2 times (P<0.05) with the significant reduction of intraoperative blood loss [55]. As a result of va-

porization of necrotized areas, purulent wound transforms into a predominantly burn wound, which accelerates the healing process (duration of all phases of the wound healing decreases by 1.5–1.8 times) and increases the likelihood of favorable outcome. Qualitative changes were also confirmed by cytological and histological examination. The non-contact character of procedures in all modes, absence of any side effects, full «compatibility» with topical medications, various wound dressings and other physical treatment methods should be considered undeniable advantages of PF [54].

In recent years, the use of laser energy in surgery has been the most popular due to laser-induced wide range of optical and photobiological effects. Both surgical and therapeutic laser modes are used in the treatment of DU. In the contaminated surgery, YAG-Ho-, CO2-, and YAG-Nd-laser systems have proved to be highly effective [56]. Due to the superthermal effect, reliable hemostasis, high quality debridement and high-energy necrolysis of the ulcerated wound surface (vaporization effect), as well as total decontamination of DU are provided. As a result of these effects, the duration of suppurative inflammation phase significantly decreases [57]. The use of a high-power and high-density laser beam is indicated for debridement [58].

Low-energy laser technology (LELT) is now successfully used for local treatment of pressure ulcers, as well as chronic non-healing purulent wounds and trophic ulcers [59–62]. The therapeutic efficacy of this technique is due to its positive effect on energy metabolism, decrease in the intensity of peroxidation, normalization of pH of the wound environment, improvement of tissue regenerative potential, lymph circulation and microcirculation in the area around the wound [61, 63] Specific biochemical mechanisms of the positive effect of LELT have been shown in the study by J. Taradaj et al. (2018) who reported expression of anti-inflammatory cytokines and increased concentration of angiogenesis factors induced by low-energy laser [62]. In addition, an antibacterial effect due to the free radical and reactive oxygen species production in the target area can be observed, which helps to combat antibiotic resistance [64]. Even a local immunomodulating effect of the technique has been noted. Thus, in the paper by M. Brauncajs et al. (2018), the anti-inflammatory effect of LELT was demonstrated when, after comparing the results of 6 patients who received a course of laser stimulation, a significant decrease in the level of protein cathelicidin LL-37 (chemoattractant for immune cells) in DU tissues was noted [65]. The authors emphasize the immunomodulatory and indirect antimicrobial properties of the technique. The use of various modes of laser energy in combination with other conservative methods allows more complete and faster preparation of deep decubitus for plastic intervention [60].

Several publications on the use of therapeutic laser in the treatment of pressure ulcers have been published recent years. Thus, S. Palagi et al. (2015) described a case report of successful conservative treatment of a patient using modern wound dressings and LELT, which reduced the size of a large decubitus ulcer from 7×6 cm to 1.5×1.1 cm [56].

Some authors suggest combining the therapeutic laser treatment with other physical methods described earlier (magnetotherapy, photodynamic treatment, ultrasonic cavitation, etc.) [28, 59]. In particular, L. Rosa et al. (2017) succeeded in achieving complete epithelialization of a deep decubitus of the heel area in an 82-year-old diabetic woman using a combination of photodynamic therapy, LELT and topical cellulose-based membranes for wound healing [66].

In a review by R. Machado et al. (2017), all known laser studies concerning DU were analyzed with a total of 386 publications found in Medline, PEDro, Cochrane, and CENTRAL databases [59]. The 4 selected and analyzed papers described LELT variations with various wavelengths (658, 808, 904, and 940 nm). The authors of the review concluded that the most significant clinical effect can be expected with regular treatment of DU with a monochromatic wave of 658 nm for 1 month. Positive experience of the use of LELT to treat various types of chronic wounds can be found in the earlier publications of Russian specialists [54, 55].

Device-based methods for accelerating the regeneration. Being the most extensive and heterogeneous group in terms of technology, these methods are widely used in phase 2 of the complicated wound process in DU. They include high-frequency low-power impulse therapy, magnetic therapy, photodynamic therapy, periodic exposure to direct electric current, hyperbaric oxygenation, ozone therapy, phonophoresis with antiseptics, ultraviolet irradiation in suberythemic doses, electrophoresis with antibacterial and anti-inflammatory drugs, treatment of pressure sores with pulsating jet [67–75]. The last three techniques have also proven to be beneficial in controlling inflammation around the wound. Although data on efficacy of individual techniques were reported in 2016–2020, the Cochrane reviews do not always confirm this positive effect. The reason may lie in methodological limitations, lack of quality fundamental works, insufficient number of observations, and/or incorrect study design. This is especially relevant for various techniques of electromagnetic stimulation and local thermal treatment of decubitus [69, 74]. Thus, when evaluating the effect of high amplitude pulsed current on decubitus ulcer,

the authors concluded that despite the positive effect of reducing the area of pressure ulcers when using complex therapy, the data needed to be confirmed by more high-quality studies due to the small number of included research trials [76]. In most studies, the assessment of effectiveness of physical methods and comparative analysis were performed on small samples (up to 40 cases). Whereas some researchers are cautiously positive about efficacy of electrostimulation for healing of pressure ulcers, but the level of evidence is not high enough for definitely recommending it to treat decubitus ulcers [77].

Combination techniques. Researchers are increasingly aware that monotherapy for treating chronic non-healing wounds has limited efficacy, so combinations of different local treatment techniques are proposed. The combination of vacuum therapy, ultrasound cavitation and hydrosurgery («VivanoTec» system, «Sonoca-180» machine and «Versajet» system, respectively) showed good results in the treatment of stage III–IV DU in 49 patients with spinal trauma (S. Shapovalov et al., 2016). The use of this combination approach reduced the treatment period by 3 times and thus accelerated the preoperative preparation for decubitus defect reconstruction [53].

Yu. Tsupikov (2007) described the results of the combined technique of DU management based on the combination of interactive or specialized wound dressings and local ozone therapy. According to the authors, this technique provides 1.3 times shorter healing time and 1.5 times shorter preparation time for reconstruction of pressure ulcers [78]. Similar studies can be found in the international literature [79]. W. Baek et al. (2020) based on statistical analysis of a small prospective sample (n=38) indicated a significant (P=0.001) acceleration of DU reduction with vacuum therapy (NPWT) and lipid-colloid wound dressings when compared with NPWT alone [26].

In 2013, A.Struchkov et al. proposed triple-component combined ozone therapy, which includes intravenous injection of ozonized saline, daily irrigation of the wound surface with an ozone-oxygen gas mixture and subcutaneous injection of the edges of the decubitus defect with this mixture. According to the authors, this technique promotes the healing of stage II and small stage III decubitus ulcers without surgical intervention in 79% of patients [67]. Furthermore, continuation of local ozone therapy sessions in the postoperative period was found to also reduce the risk of DU recurrence.

H. Duan, H. Li et al. evaluated a noteworthy combination of surgical debridement followed by extracorporeal shockwave therapy with an alginate dressing to treat stage IV DU in a patient with posthypoxic encephalopathy. The authors have emphasized efficacy and safety of this combination which could be useful for elderly patients with decubitus [80].

Conclusion

The problem of the efficient medical care for patients with pressure ulcers is still far from being resolved. In addition, due to objective reasons, we cannot expect the incidence of decubitus ulcers to decrease in clinical practice. The outcome of the conservative treatment of decubitus ulcers, with adequate correction of underlying diseases and proper care of an immobilized patient, largely depends on a local treatment. On the one hand, a variety of physical methods of wound treatment gives an opportunity to choose an individual program of DU therapy. On the other hand, each method has its limitations and contraindications, while the techniques used are not always evidence-based, clinically efficient or cost-effective. Therefore, studying and addressing the above-mentioned issues in the conservative treatment of pressure ulcers is warranted.

References

1. *Ахтямова Н.Е.* Лечение пролежней у малоподвижных пациентов. *Русский медицинский журнал.* 2015; 26: 1549–1552. [*Akhtyamova N.E.* Treatment of pressure sores in patients with limited mobility. *Russian Medical Journal.* 2015; 26: 1549–1552.]
2. *Hasegawa M., Inoue Y., Kaneko S., Kanoh H., Shintani Y., Tsujita J., Fujita H., Moteg S.I., Le Pavoux A., Asai J., Asano Y., Abe M., Amano M., Ikegami R., Ishii T., Isei T., Isogai Z., Ito T., Irisawa R., Iwata Y., Otsuka M., Omoto Y., Kato .H, Kadono T., Kawakami T., Kawaguchi M., Kukino R., Kono T., Koga M., Kodera M., Sakai K., Sakurai E., Sarayama Y., Tanioka M., Tanizaki H., Doi N., Nakanishi T., Hashimoto A., Hayashi M., Hirosaki K., Fujimoto M., Fujiwara H., Maekawa T., Matsuo K., Madokoro N., Yatsushiro H., Yamasaki O., Yoshino Y., Tachibana T., Ihn H.* Wound, pressure ulcer and burn guidelines — 1: Guidelines for wounds in general, second edition. *J Dermatol.* 2020; 47 (8): 807–833. DOI: 10.1111/1346-8138.15401. PMID: 32614097.
3. *Ayello E.A., Sibbald R.G.* From Decubitus and Pressure Ulcers to Pressure Injuries. Adv. Skin Wound Care. 2019; 32 (3): 101. DOI: 10.1097/01.ASW.0000553114.57290.be. PMID: 30801347.
4. *Boyko T.V., Longaker M.T., Yang G.P.* Review of the Current Management of Pressure Ulcers. *Adv Wound Care (New Rochelle).* 2018; 7 (2): 57–67. DOI: 10.1089/wound.2016.0697. PMID: 29392094.
5. *Magny E., Vallet H., Cohen-Bittan J., Raux M., Meziere A., Verny M., Riou B., Khiami F., Boddaert J.* Pressure ulcers are associated with 6-month mortality in elderly patients with hip fracture managed in orthogeriatric care pathway. *Arch Osteoporosis.* 2017; 12 (1): 77. DOI: 10.1007/s11657-017-0365-9. PMID: 28852954.
6. *Jaul E., Factor H., Karni S., Schiffmiller T., Meiron O.* Spasticity and dementia increase the risk of pressure ulcers. *Int Wound J.* 2019; 16 (3): 847–851. DOI: 10.1111/iwj.13110. PMID: 30895715. PMCID: PMC7948688.

7. *Thomas D.* Clinical management of pressure ulcers. *Clin. Geriatr.* Med. 2013; 29 (2): 397–413. DOI: 10.1016/j.cger.2013.01.005. PMID: 23571035.
8. *Дибиров М.Д.* Пролежни: профилактика и лечение. *Амбулаторная хирургия.* 2016; (1–2): 55–63. ISSN 2712-8741 (Print). ISSN 2782-2591 (Online)]. [*Dibirov M.D.* Decubitus: prevention and treatment. *Ambulatory Surgery (Russia) / Ambulatornaya khirurgiya.* 2016; (1–2): 55-63. ISSN 2712-8741 (Print). ISSN 2782-2591 (Online)]
9. *Blackburn J., Ousey K., Taylor L., Moore B., Patton D., Moore Z., Avsar P.* The relationship between common risk factors and the pathology of pressure ulcer development: a systematic review. J Wound Care. 2020; 29 (3): 4–12. DOI: 10.12968/jowc.2020.29. Sup3.S4. PMID: 32160123.
10. *Jaul E., Barron J., Rosenzweig J., Menczel J.* An overview of co-morbidities and the development of pressure ulcers among older adults. *BMC Geriatr.* 2018; 18 (1): 305. DOI: 10.1186/s12877-018-0997-7. PMID: 30537947.
11. *Karahan A., Abbasoğlu A., Işık S.A., Çevik B., Saltan Ç., Elbaş N., Yalılı A.* Factors Affecting Wound Healing in Individuals With Pressure Ulcers: A Retrospective Study. Ostomy Wound Manage. 2018; 64 (2): 32–39. PMID: 29481325.
12. *Mervis J.S., Phillips T.J.* Pressure ulcers: Pathophysiology, epidemiology, risk factors, and presentation. *J. Am. Acad. Dermatol.* 2019; 81 (4): 881–890. DOI: 10.1016/j.jaad.2018.12.069. PMID: 30664905.
13. *Sumarno A.S.* Pressure ulcers: the core, care and cure approach. *Br. J. Community Nurs.* 2019; 24 (Sup12): S38–S42. DOI: 10.12968/bjcn. 2019.24.Sup12.S38. PMID: 31804885.
14. *Супильников А.А., Девяткин А.А., Павлова О.Н., Гуленко О.Н.* Морфологические и физиологические аспекты течения раневого процесса (литературный обзор). *Медицинский вестник.* 2016; 23: 26–30. [*Supilnikov A.A., Devyatkin A.A., Pavlova O.N., Gulenko O.N.* Morphological and physiological aspects of the wound healing stages (literary review). *Medical Bulletin/Meditsinkiy Vestnik.* 2016; 23: 26–30. (medvestnik.ru)]
15. *Wang Y., Dai Y., Piao J., Liu C., Li M., Jiang L.* The expressions and functions of inflammatory cytokines, growth factors and apoptosis factors in the late stage of pressure ulcer chronic wounds. *Zhongguo Ying Yong Sheng Li Xue Za Zhi / Chinese journal of applied physiology.* 2017; 33 (2): 181–184. DOI: 10.12047/j.cjap.5425.2017.046.
16. *Аганесов А.Г.* Хирургическое лечение осложненной травмы позвоночника — прошлое и настоящее. *Хирургия. Журнал им. Н.И.Пирогова.* 2013; 1: 5–12. [*Aganesov A.G.* Surgical treatment of complicated spinal injury — past and present. *Pirogov Russian Journal of Surgery / Khirurgiya. Zhurnal im. N.I. Pirogova.* 2013; 1: 5–12.]
17. *Fujiwara H., Isogai Z., Irisawa R., Otsuka M., Kadono T., Koga M., Hirosaki K., Asai J., Asano Y., Abe M., Amano M., Ikegami R., Ishii T., Isei T., Ito T., Inoue Y., Iwata Y., Omoto Y., Kato H., Kaneko S., Kanoh H., Kawakami T., Kawaguchi M., Kukino R., Kono T., Kodera M., Sakai K., Sakurai E., Sarayama Y., Shintani Y., Tanioka M., Tanizaki H., Tsujita J., Doi N., Nakanishi T., Hashimoto A., Hasegawa M., Hayashi M., Fujita H., Fujimoto M., Maekawa T., Matsuo K., Madokoro N., Motegi S.I., Yatsushiro H., Yamasaki O., Yoshino Y., Le Pavoux A., Tachibana T., Ihn H.* Wound, pressure ulcer and burn guidelines — 2: Guidelines for the diagnosis and treatment of pressure ulcers, second edition. *J Dermatol.* 2020; 47 (9): 929–978. DOI: 10.1111/1346-8138.14587. PMID: 30194884.
18. *Mervis J.S., Phillips T.J.* Pressure ulcers: Prevention and management. *J Am Acad Dermatol.* 2019; 81 (4): 893–902. DOI: 10.1016/j.jaad. 2018.12.068. PMID: 30664906.
19. *Atkinson R.A., Cullum N.A.* Interventions for pressure ulcers: a summary of evidence for prevention and treatment. *Spinal Cord.* 2018; 56 (3): 186–198. DOI: 10.1038/s41393-017-0054-y. PMID: 29371701.
20. *Demarré L, Van Lancker A, Van Hecke A, Verhaeghe S, Grypdonck M, Lemey J, Annemans L, Beeckman D.* The cost of prevention and treatment of pressure ulcers: A systematic review. *Int J Nurs. Stud.* 2015; 52 (11): 1754–1774. DOI: 10.1016/j.ijnurstu.2015.06.006. PMID: 26231383.
21. *Kottner J., Cuddigan J., Carville K., Balzer K., Berlowitz D., Law S., Litchford M., Mitchell P., Moore Z., Pittman J., Sigaudo-Roussel D., Yee CY., Haesler E.* Preventionand treatment of pressure ulcers/injuries: The protocol for the second update of the international. Clinical Practice Guideline 2019. *J Tissue Viability.* 2019; 28 (2): 51–58. DOI: 10.1016/j.jtv.2019.01.001. PMID: 30658878.
22. *Kruger E.A., Pires M., Ngann Y., Sterling M., Rubayi S.* Comprehensive management of pressure ulcers in spinal cord injury: current concepts and future trends. *J. Spinal Cord Med.* 2013; 36 (6): 572–585. DOI: 10.1179/2045772313Y.0000000093. PMID: 24090179.
23. *Cerny M., Hellmich S., Schwarz-Boeger U., Schmauss D., Moog P., Bauer A.* DRG revenues and costs of multimorbid patients in the German DRG system — analysis of the surgical treatment of chronic wounds at a university hospital based on the example of pressure ulcers. *Handchir Mikrochir Plast Chir.* 2018; 50 (4): 284–290.
24. *Потекаев Н.Н., Фриго Н.В., Миченко А.В., Львов А.Н., Пантелеев А.А., Китаева Н.В.* Хронические, длительно не заживающие язвы и раны кожи и подкожной клетчатки. *Клиническая дерматология и венерология.* 2018; 17 (6): 7–12. DOI: 10.17116/klinderma2018170617. [P*otekaev N.N., Frigo N.V., Mishchenko A.V., Lvov A.N., Panteleev A.A., Kitaeva N.V.* Chronic, long-term non-healing ulcers and wounds of the skin and subcutaneous tissue. *Russian Journal of Clinical dermatology and venereology/ Klinicheskaya dermatologiya i venerologiya.* 2018; 17 (6): 7–12. https://doi.org/10.17116/klinderma2018170617.]
25. *Taradaj J.* Prevention and treatment of pressure ulcers by newest recommendations from European pressure ulcer advisory panel (EPUAP): practical reference guide for GPs. *Fam Med Prim Care Rev.* 2017; 19 (1): 81–83. DOI: 10.5114/fmpcr.2017.65097.
26. *Baek W., Lee N., Han E.J., Roh T.S., Lee WJ.* A Prospective Randomized Study: The Usefulness and Efficacy of Negative Pressure Wound Therapy with Lipidocolloid Polyester Mesh Compared to Traditional Negative Pressure Wound Therapy for Treatment of Pressure Ulcers. *Pharmaceutics.* 2020; 12 (9): 813. DOI: 10.3390/pharmaceutics 12090813. PMID: 32867251.
27. *Chapman S.* Preventing and treating pressure ulcers: evidence review. *Br. J. Community Nurs.* 2017; 22 (3): S37–S40. DOI: 10.12968/ bjcn.2017.22.Sup3.S37. PMID: 28252342.
28. *Damert H., Meyer F., Altmann S.* Therapeutic options for pressure ulcers. Review. *German Zentralbl. Chir.* 2015; 140 (2): 193–200. DOI: 10.1055/s-0035-1545808. PMID: 25874469.
29. *Gupta S., Andersen C., Black J., de Leon J., Fife C., Lantis JC., Niezgoda J., Snyder R., Sumpio B., Tettelbach W., Treadwell T., Weir D, Silverman RP.* Management of Chronic Wounds: Diagnosis, Preparation, Treatment, and Follow-up. *Wounds.* 2017; 29 (9): S19–S36. PMID: 28862980.
30. *Hao X.Y., Li H.L., Su H., Cai H., Guo T.K., Liu R., Jiang L., Shen Y.F.* Topical phenytoin for treating pressure ulcers. *Cochrane Database Syst. Rev.* 2017; 2 (2): CD008251. DOI: 10.1002/14651858.CD008251.pub2. PMID: 28225152.
31. *McCallon S.K., Frilot C.* A retrospective study of the effects of clostridial collagenase ointment and negative pressure wound therapy for the treatment of

chronic pressure ulcers. *Wounds*. 2015; 27 (3): 44–53. PMID: 25786076.
32. *Carter M.J., Gilligan A.M., Waycaster C.R., Schaum K., Fife C.E.* Cost effectiveness of adding clostridial collagenase ointment to selective debridement in individuals with stage IV pressure ulcers. *J Med Econ* 2017; 20 (3): 253–265. DOI: 10.1080/13696998.2016.1252381. PMID: 27774840.
33. *Moore Z.E., Webster J.* Dressings and topical agents for preventing pressure ulcers. *Cochrane Database Syst. Rev.* 2018; 12 (12): CD009362. DOI: 10.1002/14651858.CD009362.pub3. PMID: 30537080.
34. *Headlam J., Illsley A.* Pressure ulcers: an overview. *Br J Hosp Med.* 2020; 81 (12): 1–9. DOI: 10.12968/hmed.2020.0074. PMID: 33377838.
35. *Junior W.* Alginate dressings for treating pressure ulcers. *Sao Paulo Med. J.* 2015; 133 (5): 455. DOI: 10.1590/1516-3180.20151335T2. PMID: 26648438.
36. *Stolt M., Hjerppe A., Hietanen H., Puukka P., Haavisto E.* Local treatment of pressure ulcers in long-term care: a correlational cross-sectional study. *J W3ound Care.* 2019; 28 (6): 409–415. DOI: 10.12968/ jowc.2019.28.6.409. PMID: 31166863.
37. *Walker R.M., Gillespie B.M., Thalib L., Higgins N.S., Whitty J.A.* Foam dressings for treating pressure ulcers. *Cochrane Database Syst. Rev.* 2017; 12 (10): CD011332. DOI: 10.1002/14651858.CD011332.pub2. PMID: 29025198.
38. *Westby M.J., Dumville J.C., Soares M.O., Stubbs N., Norman G.* Dressings and topical agents for treating pressure ulcers. *Cochrane Database Syst. Rev.* 2017; 6 (6): CD011947. DOI: 10.1002/14651858. CD011947.pub2. PMID: 28639707.
39. *Boyko T.V., Longaker M.T., Yang G.P.* Review of the Current Management of Pressure Ulcers. *Adv Wound Care* 2018; 7 (2): 57–67. DOI: 10.1089/wound.2016.0697. PMID: 29392094.
40. *Biglari B., Heller R.A., Grützner P.A., Moghaddam A., Badke A.* Therapy and prevention of pressure ulcers in paraplegics. *Neurol Rehabil* 2018; 24 (1): 32-41. https://www.researchgate.net/publication/323588750_Therapy_and_prevention_of_pressure_ulcers_in_paraplegics.
41. *Andrianasolo J., Ferry T., Boucher F., Chateau J., Shipkov H., Daoud F., Braun E., Triffault-Fillit C., Perpoint T., Laurent F., Mojallal A.A., Chidiac C., Valour F.* Pressure ulcer-related pelvic osteomyelitis: evaluation of a two-stage surgical strategy (debridement, negative pressure therapy and flap coverage) with prolonged antimicrobial therapy. *BMC Infect. Dis.* 2018; 18 (1): 166–170. DOI: 10.1186/s12879- 018-3076-y. PMID: 29636030.
42. *Dumville J.C., Webster J., Evans D., Land L.* Negative pressure wound therapy for treating pressure ulcers. *Cochrane Database Syst. Rev.* 2015; 20 (5): CD011334. DOI: 10.1002/14651858.CD011334.pub2. PMID: 25992684.
43. *Stryja J., Staffa R., Říha D., Stryjová K., Nicielniková K.* Cost-effectiveness of negative pressure wound therapy in outpatient setting [Article in Czech]. *Rozhl. Chir.* 2015; 94 (8): 322–328. PMID: 26395955.
44. *Горюнов С.В., Абрамов И.С., Чапарьян Б.А., Егоркин М.А., Жидких С.Ю.* Руководство по лечению ран методом управляемого отрицательного давления. М.: *Русский врач*; 2013: 130. ISBN 978-5-905212-26-0. [*Goryunov S.V., Abramov I.S., Chaparyan B.A., Egorkin M.A., Zhidkikh S.Yu.* Guidelines for the treatment of wounds by controlled negative pressure. [in Russ] Moscow: *Russian Doctor/Russkiy Vrach*; 2013: 130. ISBN 978-5-905212-26-0.].
45. *Song Y.-P., Wang L., Yuan B.-F., Shen H.-W., Du L., Cai J.-Y., Chen H.-L.* Negative-pressure wound therapy for III/IV pressure injuries: A meta-analysis. *Wound Repair Regen.* 2021; 29 (1): 20–33. DOI: 10.1111/wrr.12863. Epub 2020 Oct 12. PMID: 32989919.
46. *Lima R.V.K.S., Coltro P.S., Júnior J.A.F.* Negative pressure therapy for the treatment of complex wounds. *Rev Col Bras Cir.* 2017; 44 (1): 81–93. DOI: 10.1590/0100-69912017001001. PMID: 28489215.
47. *Stojmenski S., Merdzanovski I., Gavrilovski A., Pejkova S., Dzokic G., Tudzarova S.* Treatment of decubitis ulcer stage IV in the patient with polytrauma and vertical share pelvic fracture, diagnosed entherocollitis and deep wound infection with Clostridium difficile with combined negative pressure wound therapy (NPWT) and faecal management system: Case report. *Maced J Med Sci.* 2017; 5 (3): 349–351. DOI: 10.3889/oamjms.2017.060. PMID: 28698756.
48. *Giri P., Krishnaraj B., Chandra Sistla S., Sistla S., Basu D., Shankar G., Akkilagunta A., Ruparelia J.* Does negative pressure wound therapy with saline instillation improve wound healing compared to conventional negative pressure wound therapy? — A randomized controlled trial in patients with extremity ulcers. *Ann Med Surg.* 2020; 61: 73–80. DOI: 10.1016/j.amsu.2020.12.015. PMID: 33408857.
49. *Arowojolu O.A., Wirth G.A.* Sacral and Ischial Pressure Ulcer Management With Negative-Pressure Wound Therapy With Instillation and Dwell. *Plast Reconstr Surg.* 2021; 147 (1S-1): 61S–67S. DOI: 10.1097/PRS.0000000000007613. PMID: 33347064.
50. *Gao X.-Q., Xue X.-M., Zhang J.-K., Yan F., Mu Q.-X.* Effectiveness of High Frequency Ultrasound on Pressure Ulcer: A Systematic Review Protocol of Randomized Controlled Trial. *Medicine (Baltimore).* 2019; № 98 (37): e17111. DOI: 10.1097/MD.0000000000017111. PMID: 31517845.
51. *Kataoka Y., Kunimitsu M., Nakagami G., Koudounas S., Weller C. D., Sanada H.* Effectiveness of ultrasonic debridement on reduction of bacteria and biofilm in patients with chronic wounds: A scoping review. *Int Wound J.* 2021; 18 (2): 176–186. DOI: 10.1111/iwj.13509. PMID: 33236843.
52. *Налбандян Р.Т., Митиш В.А., Мединский П.В., Никонов А.В.* Гидрохирургическая обработка ран. *Детская хирургия.* 2016; 20 (3): 160-163. УДК: 617-001.4-089.819 Издательство «Медицина». ISSN: 1560-9510. eISSN: 2412-0677. [*Nalbandian R.T., Mitish V.A., Medinsky P.V., Nikonov A.V.* Hydrosurgical treatment of wounds. *Pediatric surgery/Detskaya Khirurgia.* 2016; 20 (3): 160–163. UDC: 617-001.4-089.819]
53. *Шаповалов С.Г., Сухопарова Е.П.* Хирургическая реабилитация пациентов с декубитальными язвами. *Ученые записки СПбГМУ. им. Акад. И.П.Павлова.* 2016; 23 (3): 35–39. [*Shapovalov S.G., Sukhoparova E.P.* Surgical rehabilitation of patients with decubital ulcers. *Scientific notes of The First Pavlov State Medical University of St. Petersburg.* 2016; 23 (3): 35–39.]
54. *Шулутко А.М., Османов Э.Г., Качикин А.С.* Плазменная хирургическая технология — возможности и перспективы применения. М.: *Наука*; 2017: 238 с. ISBN 978-5-600-01784-9. [*Shulutko A.M., Osmanov E.G., Kachikin A.S.* Plasma flow surgical technology — potential and prospects of application. Moscow: Nauka; 2017: 238s. ISBN 978-5-600-01784-9.]
55. *Шулутко А.М., Османов Э.Г., Чантурия М.О., Мачарадзе А.Д.* Плазменные потоки в хирургической практике. *Русский Медицинский журнал.* 2018; 2 (24): 93-98. DOI: 10.18821/0869-2106-2018-24-2-93-98. [*Shulutko A.M., Osmanov E.G., Chanturia M.O., Macharadze A.D.* Plasma flows in surgical practice. *Russian Medical Journal.* 2018; 2 (24): 93–98. DOI: 10.18821/0869-2106-2018-24-2-93-98]
56. *Palagi S., Severo I.M., Menegon D.B., Lucena A.F.* Laser therapy in pressure ulcers: evaluation by the Pressure Ulcer Scale for Healing and Nursing Outcomes Classification. *Rev. Esc. Enferm. USP.* 2015; 49 (5): 826–833. DOI: 10.1590/S0080-623420150000500017. PMID: 26516754.

57. *Lu Q., Yin Z., Shen X., Li J., Su P., Feng M., Xu X., Li W., He C., Shen Y.* Clinical effects of high-intensity laser therapy on patients with chronic refractory wounds: a randomised controlled trial. *BMJ Open.* 2021; 11 (7). DOI: 10.1136/bmjopen-2020-045866.
58. *Hajhosseini B., Chiou G.J., Dori G., Fukaya E., Chandra V., Meyer S., Gurtner G.C.* Er: YAG laser vs. sharp debridement in management of chronic wounds: effects on pain and bacterial load. *Wound Repair Regen.* 2020; 28 (1): 118–125. DOI: 10.1111/wrr.12764. PMID: 31587431.
59. *Machado R.S., Viana S., Sbruzzi G.* Low-level laser therapy in the treatment of pressure ulcers: systematic review. *Lasers Med. Sci.* 2017; 32 (4): 937–944. DOI: 10.1007/s10103-017-2150-9. PMID: 28116536.
60. *Яковлева А.В., Яковлев А.А., Петрова М.В., Крылов К.Ю.* Случай применения комплексного способа лечения декубитальной язвы у пациента в хроническом критическом состоянии. *Вестник РГМУ*. 2019; 3: 39–43. DOI: 10.24075/vrgmu. 2019.035. [*Yakovleva A.V., Yakovlev A.A., Petrova M.V., Krylov K.Yu.* A comprehensive decubital ulcer management in a patient with chronic critical illness. Clinical case. *Bulletin of RSMU/Vestnik RGMU*. 2019; 3: 39–43. DOI: 10.24075/vrgmu.2019.035.]
61. *Andrade F.S.S.D., Clark R.M.O., Ferreira M.L.* Effects of low-level laser therapy on wound healing. *Rev Col Bras Cir.* 2014; 41 (2): 129–133. DOI: 10.1590/s0100-69912014000200010. PMID: 24918727.
62. *Taradaj J., Shay B., Dymarek R., Sopel M., Walewicz K., Beeckman D., Schoonhoven L., Gefen A., Rosińczuk R.* Effect of laser therapy on expression of angio- and fibrogenic factors, and cytokine concentrations during the healing process of human pressure ulcers. *Int. J. Med Sci.* 2018; 15 (11): 1105–1112. DOI: 10.7150/ijms.25651. PMID: 30123047. PMCID: PMC6097266.
63. *Fukuda T.Y., Tanji M.M., Silva S.R., Sato M.N., Plapler H.* Infrared low-level diode laser on inflammatory process modulation in mice: pro- and anti-inflammatory cytokines. *Lasers Med. Sci.* 2013; 28 (5): 1305–1313. DOI: 10.1007/s10103-012-1231-z. PMID: 23179306.
64. *Wang C., Huang S., Zhu T., Sun X., Zou Y., Wang Y. [*Efficacy of photodynamic antimicrobial therapy for wound flora and wound healing of pressure sore with pathogen infection]. *Zhonghua Yi Xue Za Zhi* (Chinese). 2014; 94 (31). 2455–2459. PMID: 25400056.
65. *Brauncajs M., Ksiąszczyk K., Lewandowska-Polak A., Gorzela K., Grzegorczyk J.* Impact of low-level laser therapy on the dynamics of pressure ulcer-induced changes considering an infectious agent and cathelicidin LL-37 concentration: a preliminary study. *Postepy Dermatol. Alergol.* 2018; 35 (6): 582–586. DOI: 10.5114/ada.2018.77609. PMID: 30618525.
66. *Rosa L.P., da Silva F.C., Vieira R.L., Tanajura B.R., da Silva Gusmão A.G., de Oliveira J.M., Dos Santos N.A.C., Bagnato V.S.* Application of photodynamic therapy, laser therapy, and a cellulose membrane for calcaneal pressure ulcer treatment in a diabetic patient: a case report. *Photodiagnosis Photodyn. Ther.* 2017; 1 (9): 235–238. DOI: 10.1016/ j.pdpdt.2017.06.011. PMID: 28666974.
67. *Стручков А.А., Морозов И.Н.* Применение методов озонотерапии при лечении пролежней. *Медицинский альманах.* 2013; 3 (27): 122–123. [*Struchkov A.A., Morozov I.N.* Application of ozone therapy in management of bedsores. *Medical almanac/Meditcinsky almanah.* 2013; 3 (27): 122–123.] ISSN 1997-7689 (Print), ISSN 2499-9954 (Online).
68. *Arora M., Harvey L.A., Glinsky J.V., Nier L., Lavrencic L., Kifley A., Cameron I.D.* Electrical stimulation for treating pressure ulcers. *Cochrane Database Syst Rev.* 2020; 1 (1): CD012196. DOI: 10.1002/14651858. CD012196.pub2. PMID: 31962369.
69. *Aziz Z, Bell-Syer S.E.M.* Electromagnetic therapy for treating pressure ulcers. *Cochrane Database Syst Rev.* 2015; (9): CD002930. DOI: 10.1002/14651858. CD002930.pub6. PMID: 26334539.
70. *Bogie K.M., Ho C.H.* Pulsatile lavage for pressure ulcer management in spinal cord injury: a retrospective clinical safety review. *Ostomy Wound Manage.* 2013; 59 (3): 35-38. PMID: 23475450.
71. *Kan Y., Zhang X.-N., Jing X.-H.* Research progress of acupuncture and the related adjuvant therapy for promoting pressure ulcer healing in recent 10 years. *Zhongguo Zhen Jiu.* 2019. 39 (6): 680–684 (Chinese). DOI: 10.13703/j.0255-2930.2019.06.031. PMID: 31190509.
72. *Petz F.F.C, Félix J.V.C., Roehrs H., Pott F.S, Stocco J.G.D., Marcos R.L.,Meier M.J.* Effect of Photobiomodulation on Repairing Pressure Ulcers in Adult and Elderly Patients: A Systematic Review. *Photochem Photobiol.* 2020; 96 (1): 191–199. DOI: 10.1111/php.13162. PMC6485618. PMID: 31550398.
73. *Polak A., Kloth L.C., Blaszczak E., Taradaj J., Nawrat-Szoltysik A., Ickowicz T., Hordynska E., Franek A., Kucio C.* The Efficacy of Pressure Ulcer Treatment With Cathodal and Cathodal-Anodal High-Voltage Monophasic Pulsed Current: A Prospective, Randomized, Controlled Clinical Trial. *Phys Ther.* 2017; 97 (8): 777–789. DOI: 10.1093/ptj/ pzx052. PMID: 28789467.
74. *Yue J.-H., Zhang S.-J., Sun Q., Sun Z.-R., Wang X.-X., Golianu B., Lu Y., Zhang Q.* Local warming therapy for treating chronic wounds: a systematic review. *Medicine (Baltimore).* 2018; 97 (12): e9931. DOI: 10.1097/MD.0000000000009931. PMID: 29561463.
75. *Zhang Q.-H., Yue J.-H., Sun Z.-R.* Electroacupuncture for pressure ulcer: a study protocol for a randomized controlled pilot trial. *Trials.* 2014; (15): 7. DOI: 10.1186/1745-6215-15-7. PMID: 24393344.
76. *Zhang Z., Li B., Wang Z., Wu L., Song L., Yao Y.* Efficacy of bimodal high-voltage monopulsed current in the treatment of pressure ulcer: a systematic review. *Iran J Public Health.* 2019; 48 (11): 1952–1959. PMID: 31970093. PMCID: PMC6961193.
77. *Arora M., Harvey L.A., Glinsky J.V., Nier L., Lavrencic L., Kifley A., Cameron I.D.* Electrical stimulation for treating pressure ulcers. *Cochrane Database Syst Rev.* 2020; (1): CD012196. DOI: 10.1002/ 14651858.CD012196. pub2. PMID: 31962369. PMCID: PMC6984413.
78. *Цуников Ю.М., Поройский С.В., Буданова Л.С.* Оптимизация лечения пролежней в условиях нейрохирургического стационара. Вятский медицинский вестник. 2007; 1: 15–19.
79. *Meier C., Boes S., Gemperli A., Gmünder H.P.* Treatment and cost of pressure injury stage III or IV in four patients with spinal cord injury: the Basel Decubitus Concept. *Spinal Cord Ser Cases.* 2019; 30 (5): 30–36. DOI: 10.1038/s41394-019-0173-0. PMID: 31632697.
80. *Duan H., Li H., Liu H., Zhang H., Liu N., Dong Q., Li Z.* Extracorporeal shockwave therapy combined with alginate dressing for treatment of sacroiliac decubital necrosis in older adults: A case report. Medicine (Baltimore) 2020; 99 (19): e19849. DOI: 10.1097/MD. 0000000000019849. PMID: 32384429. PMCID: PMC7220157.

Received 26.08.2021
Accepted 07.02.2022