43 Negative Pressure Wound Therapy

Giulia Davini and Marco Romanelli

43.1 History of Negative Pressure Wound Therapy

For clinical use of NPWT, we need to go back to about thousands of years ago, when it was first used in Chinese medicine in addition to acupuncture techniques. In 1841, Junod, to "stimulate circulation," adopted the method of heated cups that were applied directly to the patient's skin. It was observed that with the cooling of the air, a subatmospheric pressure was created inside the cups, which caused hyperemia [1].

This discovery represented a real source of inspiration for the researchers who later undertook numerous studies in this regard. In particular, we remember the actual authors of NPWT Michael Morykwas and Louis Argenta. They designed a series of animal studies, using NPWT with a polyurethane foam dressing, which served as an interface between the wound surface and the vacuum source [2]. So the foam proved to be the fundamental tool of the system, as it guaranteed a uniform distribution of pressure over the entire surface of the wound. In addition, the volume of the foam is reduced by pressure and causes the stretching of the cells, the contraction of the wound, and the elimination of fluids. Since then, numerous variants of NPWT have been registered [1]. In 1993, Fleischmann applied topical negative pressure to wounds via a long-term foam dressing to promote granulation and tissue repair in 15 patients with open fractures [3]. He was able to observe an efficient wound cleansing without bone infections (although one of the patients suffered a soft tissue infection). In his first studies, the negative pressure inside the wound was obtained through a simple suction unit mural or with portable vacuum cleaners for surgery. However, these devices have led to practical problems in terms of achieving, controlling, and maintaining the desired levels of negative pressure. At a distance of a century and more from the first description of the cellular world, great progress has been made in understanding the cellular and molecular mechanisms responsible for the healing of wounds. In carrying out this research, numerous factors have emerged that cause difficult healing of wounds such as the lack of local and systemic growth factors, changes in the extracellular matrix, decreased functionality of fibroblasts, and reduced antimicrobial activity of leukocytes. These aspects have attracted considerable interest from the researchers, who later studied new specific products, which act in a targeted way, based on the wound bed, ensuring the greatest possible benefit [4].

Products of this kind such as hydrocolloids, hydrogels, alginates, and polyurethane foams are used in fact in dressings, which today are

G. Davini · M. Romanelli (✉)
Department of Dermatology, University of Pisa, Pisa, Italy

M. Fimiani et al. (eds.), *Technology in Practical Dermatology*,
https://doi.org/10.1007/978-3-030-45351-0_43

called "advanced." Instead, we must wait until the end of the 1990s for NPWT, which I will mention in my thesis.

43.2 Description of the Device and Mechanism of Action

The acronym "VAC" literally means "vacuum assisted closure," which consists of an advanced and non-invasive system, composed of several elements that work mechanically in order to promote the healing of a wound or injury. The fundamental characteristic of this device is the application of the negative topical pressure, i.e., a pressure lower than the atmospheric pressure, normally present at ambient temperature above sea level, where the molecules exert a force that corresponds exactly to the pressure of 760 mmHg. The therapeutic system [4] is provided with a black, hydrophobic, open pores polyurethane (PU) foam dressing which is introduced into the lesion. Alternatively, a hydrophilic polyvinyl alcohol foam can be used, with more dense and smaller pores (the choice of foam type depends on the wound characteristics and treatment objectives). To isolate this dressing, a semi-occlusive and transparent adhesive film is used, which adheres to the healthy skin around the lesion. To this film a small hole is made, in which a small tube is inserted and anchored by an adhesive disk (pad). The tube is connected to a suction system, which ends in a container (canister). It collects the exudate drained through the foam and thanks to the negative pressure, which is generated by an electrically powered therapeutic unit [4]: through a rotary valve, it continuously transfers the gaseous molecules from the input to the output of the device. The negative pressure, in fact, is obtained by removing the gaseous molecules from the affected area (for example the wound site), using a suction pump. Within this electric therapeutic unit there is a microprocessor, which has the function of capturing any pressure changes and transmitting the alarm through the "central." This equipment is provided with an interface and control module (for operations of "input and output" of the data), a parameters already set, and a "touch" display.

The polyurethane foam is placed in the wound and, after activating of NPWT (125 mmHg), it contracts. Reducing its volume and still maintaining the porosity under suction, the foam provides a uniform pressure on the entire bed of the lesion. This involves the elimination of edema from the perilesional tissues, the increase in blood flow, and the stimulation of the angiogenesis. The contraction of the foam draws close and stabilizes the wound margins, thus providing an anchor point for the muscles and the deeper structures. With the application of NPWT, the exudate, inhibitory substances, and small residues are removed from the lesion, providing a suitable environment for healing.

The environment of the lesion [5] is a microcosm that develops between an area of the body before the skin barrier and the medication adhered to it. Cell regeneration, particularly in a second intention healing, occurs according to a process called "frog leap," i.e., the dermal cells migrate from the edges and the bottom of the lesion towards the center. To fill the empty space, due to the lack of tissue, the new cells glide on each other.

In the dry environment the epithelium migrates slowly between the dried dermis and the subcutaneous adipose tissue, separating the intermediate tissues; while in the wet one the migration occurs between the right amount of exudate and the dermis. This result was obtained thanks to the "Moist Wound Healing" theory elaborated in 1962 by George Winter [6, 7]; following a study that highlighted the reparative principles previously described, he stated that: "…covering a wound with a film impermeable to water vapor has profoundly changed the pattern of healing, directing the migration of the epidermis on the wound rather than through the dermis, accelerating epidermal regeneration."

43.3 Physiopathological Effects

In its simplest form, the TNP system offers a sophisticated, sterile and airtight dressing, whose properties create a moist healing environment. Other effects are [4]:

- increase in local blood flow
- reduction of edema

- stimulation of granulation tissue
- stimulation of cell proliferation
- elimination of soluble healing inhibitors from the wound
- reduction of bacterial load
- rapprochement of wound edges

Some factors [5] have a considerable influence on the evolution of a wound or injury:

- the nutritional status of the person (vitamin C plays an important role in the synthesis of collagen).
- the presence of metabolic diseases (i.e., diabetes) slows down the healing process.
- circulatory deficits related to venous stasis or atherosclerosis cause an inadequate blood supply.
- different diseases inhibit repair.

In order to talk concretely about the NPWT system, it is essential to expose the results that it provides at the tissue level. This type of dressing is characterized by a hermetic seal obtained by the film and by the tube connected to the suction device; this allows you to create a moist environment conducive to healing. In particular, treatment with NPWT therapy provides important physiopathological effects.

43.4 Clinical Evidence on NPWT

Morykwas et al. [2] studied the effect of NPWT therapy on local blood flow by inducing deep wounds on pig tissues and then medicating them with polyurethane foam. The results obtained indicate that with a negative pressure of 125 mmHg the blood supply is quadrupled. With higher pressures, there is a risk that the capillaries deform and the blood flow decreases. In fact, with the application of negative pressures of 400 mmHg or more, the spraying was inhibited. Timmers et al. [8] examined the effect of TNP therapy on the spraying of healthy skin of ten voluntary subjects. They evaluated the TNP based on the medication used. It emerged that a negative pressure up to 300 mmHg with polyurethane foam increases also of five times the blood circulation, while with foam in polyvinyl alcohol the increase is tripled. The difference in the results of the research carried out is due to the smaller pore size of the polyvinyl foam, which attenuates the effect of the NPWT. Various other factors influence the level of pressure reached in the wound bed: it will be reduced for example into case of clot formation, hemorrhage, and interposed dressing layers.

Another pathophysiological effect of NPWT is the stimulation of granulation tissue formation. By conducting other studies on pigs, it was found not only that comparing the standard medications with NPWT [9], the latter obtains a better outcome, but also that comparing a continuous and intermittent treatment with NPWT, the second responds more effectively [4]. It is important to point out that the optimal result is achieved by applying a continuous pressure to the first 48 hours and then proceeding with the intermittent pressure for any type of dressing. In particular in the wounds that produce abundant exudate, a continuous pressure will be applied because it allows to keep the dressing well sealed and cleansed. This result is due to the fact that the continuous pressure incessantly stimulates the cells, which in a sense, adapt to the forces and no longer react.

Some clinicians recommend using the continuous setting for the first 48 hours of therapy while maintaining a pressure of 125 mmHg before switching to intermittent mode [10].

Mechanical stress induces proliferation and cell division [11]. For many years, plastic and orthopedic surgeons have used this effect in order to expand soft tissue and stretch the bones [12]. This is also one of the most important features of NPWT therapy; a computer model showed that the negative pressure induces micro-deformations in the tissues inside the wound, and this has also been observed in the clinical context. This mechanical stretching of the cells stimulates proliferation and accelerates wound healing. In chronic wounds, this mechanism stimulates angiogenesis and epithelization [13].

Fabian et al. also observed an angiogenesis improvement and a tendency to increase the epithelialization rate with the TPN used in an experimental model on rabbits [14]. TPN promotes an active healing state by eliminating harmful components (such as cytokines and matrix metalloproteinases) associated with excess exudate in no-healing wounds [13, 15, 16].

Therapy can also contribute to the reduction of bacterial load. The hermetic closure formed by foam and film, for example, reduces the risk of contamination from the outside, while the improvement of blood supply can increase the resistance to infection.

Regarding the wound infection, it has always been considered a contraindication to negative pressure therapy.

However, the evidence suggests that NPWT may play a role in reducing the bacterial load within the wound and reducing the levels of exotoxins and endotoxins potentially harmful thanks to the simple and rapid removal of the exudate from the wound. Being the NPWT mechanism a closed system, the unpleasant odors and bacterial contamination also decrease during dressing change [4].

Negative pressure therapy has been shown to be an effective adjuvant method for the treatment of postoperative wound infection after a median sternotomy [17, 18].

Mehbod et al. reported similar positive outcomes for infected spinal surgical wounds, even in the presence of implanted material [19], and Dosluoglu et al. obtained encouraging results using the NPWT combined with debridement to manage the infected vascular prostheses [20]. Schimp et al. also reported advantages obtained with NPWT in the management of complex surgical wounds in the field of oncology and gynecology [21]. However, these are unusually complicated wounds, which are not one of the main indications of TNP.

For any wound in which it is difficult to manage the exudate, NPWT should be considered as a therapeutic option along with other treatments. The NPWT system has been considered, for example, as an effective method to protect the skin from the effluents that escape from a fistula, although this does not come within the range of uses provided by the manufacturer [22, 23].

When applied correctly, NPWT also has the advantage of avoiding the flow of the exudate into the wound and consequently the increase in bacterial load and the accumulation of fluid rich in potentially harmful proteases in the deep cavities of the wound. The accumulation of fluid and the spread of sepsis are a major problem in cavitary wounds, and this may explain the validity of NPWT in the management of minor amputations of the diabetic foot or pressure ulcers.

A final physiopathological effect is represented by the partial vacuum created by NPWT, which causes the contraction of the foam and the consequent rapprochement of the wound margins towards the center, facilitating its closure [4].

This therapy, used after careful wound assessment and appropriately used, is a valuable tool because its mechanisms have a substantial impact on many of the factors that contribute to healing.

43.5 Indications and Contraindications

The use of NPWT is indicated in many types of acute and chronic wounds and can benefit many patients both for the treatment of symptoms and for wound healing. NPWT can be considered when the wound:

- does not progress towards healing on schedule, for example when the contraction of wound margins occurs too slowly with standard care.
- produces an excessive amount of exudate, difficult to treat.
- it is localized in a discomforting point or it has a dimension that makes an adequate sealing with traditional dressings problematic.
- requires a reduction in size before proceeding with a surgical closure [4, 9].

The use of NPWT is also indicated in cases where the patient requires a dressing or treatment firmly positioned on the lesion and does not require frequent changes, for example in cases of injury in children, for which close changes of the dressing can be traumatic or the dressings may not remain firm in their place [24, 25]. Moreover, in the case of certain types of wounds, or in the presence of skin grafts, the NPWT has a splinting effect (rigid support) [26, 27].

Many successes of NPWT are reported in the literature, but there are situations in which the wrong choice or inappropriated application of NPWT can result in poor clinical outcomes or adverse events. Therefore, to avoid the safe and effective use of this technique, contraindications have been listed as:

- osteomyelitis.
- neoplastic lesions as it can stimulate the proliferation of neoplastic cells.
- non-enteric fistulas not explored as there may be communication with vulnerable underlying organs.
- vessels, nerves, anastomoses, or exposed organs as if applied directly to exposed structures, due to the force of the negative pressure, the NPWT can cause injury or break vessels.
- necrotic tissue with the presence of eschar or thick slough in the wound bed, since before the application it is necessary to perform a proper debridement obtaining more rapid results [28].
- We have also listed some precautions on which it is necessary to pay attention as:
- delicate blood vessels since direct negative pressure can cause a trauma to the vessel and bleeding.
- delicate structures exposed, in fact patients with exposed blood vessels, bands, tendons, or ligaments can cause bleeding and trauma.
- bleeding: wounds with active bleeding or for whom the patient is at high risk of bleeding, or is receiving anticoagulant therapy and/or platelet aggregation inhibitors, negative pressure therapy may cause bleeding due to increase of local perfusion, and consequently the loss of blood would be greater.
- patients with enteric fistulae.
- patients requiring special therapies or treatments such as magnetic resonance and hyperbaric therapy [28] (Table 43.1).

Table 43.1 Indications and contraindications for NPWT

Indications	Contraindications
• Those who have been deemed a candidate for adjunctive therapies, see "determining candidacy for adjunctive therapies"	• Presence of necrotic and fibrotic tissue
	• Untreated osteomyelitis
	• Malignant wounds
• Wound types:	• Localized ischemia
– Diabetic foot ulcers (IB)	• High output, non-enteric and unexplored fistulas
– Pressure injuries	
– Surgical wounds	• In the absence of appropriate blood supply
– Grafts and flaps	• Severe excoriation of periwound
– Traumatic wounds	• Do not place dressings in direct contact with exposed blood vessels, anastomotic sites, organs or nerves
– Partial-thickness burns	
– Pilonidal sinus wounds	
– Necrotizing fasciitis	• Do not place dressings into blind/unexplored tunnels
• To accelerate the formation of granulation tissue	• Stop therapy if person experiences autonomic dysreflexia
• To improve perfusion through removal of excess interstitial fluid	• Do not place therapy in proximity to the vagus nerve
• To reduce bacterial colonization	• Do not over fill the wound with dressing material
• To enhance epithelial migration	

43.6 Portable NPWT Systems

Smaller disposable NPWT devices are developed in order to manage it not only in the hospital, but also in community care.

Awad and Butcher [29] used a portable NPWT device (SNaP® device Spiracur) in a patient with diabetic foot ulceration with an extensive re-ulceration overlying a previous amputation.

The patient was able to maintain self-care and to keep working during the last stages of the management. The results showed the absence of infection, the improvement of peri-wound skin health, and the reduction of wound size.

The SNaP® system uses spring mechanism to generate consistent levels of pressure to achieve pre-determined levels of subatmospheric pressure (−75 mmHg, −100 mmHg, and −125 mmHg) [30] at the wound interface. The system is silent, light, disposable, portable, and easy to manage and it can be used in moderately exuding wounds (less than 120 mls/week).

PICO® (Smith and Nephew Healthcare) is another lightweight portable, negative pressure system that produces negative pressure at −80 mmHg continuously through two AA batteries providing power to the device. The system can be used for wounds that produce few exudate.

(up to 300mls per week) and may be managed with gauze or foam fillers. Because of the absence of canister, fluids are absorbed and moved to the top surface of the dressing, where the moisture vapor is then evaporated through the film. The device is easy to use but has limitations about wound size and wounds on flat body surfaces as the dressing cannot be cut or modified.

Prevena™ Incision Management System (KCI) is a NPWT device that is used on surgical incisions in order to drain until the comple closures. Prevena™ is intended to be applied immediately post-surgery to clean closed incisions for a minimum of 2 days and up to a maximum of 7 days. It should be noted that due to low amounts of silver contained in the dressing the device is unsuitable for people with a silver sensitivity [31].

43.7 Conclusions

Used in conjunction with conventional therapies and after a careful wound assessment, NPWT is a valuable tool for both the doctor and the patient.

NPWT should be considered as an important component of the overall management of a wound, to be chosen on the basis of a strategy comprising defined objectives and outcomes [32]. It should be interrupted when these objectives have not been achieved, if the treatment does not have the desired effects and if it is not tolerated by the patient and it causes complications.

Conflict of Interest The authors declare no conflict of interest for this chapter.

References

1. Banwell P, Téot L. Topical negative pressure (TNP) therapy. First international topical negative pressure (TNP) therapy focus group meeting proceedings. London: TXP Communications; 2004.
2. Morykwas MJ, Argenta LC, Shelton-Brown EI, et al. Vacuum-assisted closure: a new method for wound control and treatment: animal studies and basic foundation. Ann Plast Surg. 1997;38(6):553–62.
3. Fleischmann W, Strecker W, Bombelli M, et al. Vacuum sealing as treatment of soft tissue damage in open fractures. Unfallchirurg. 1993;96(9):488–92.
4. European Wound Management Association (EWMA). Position Document: Negative pressure wound therapy for the management of chronic wounds. London: MEP Ltd, 2007.
5. Regione Emilia Romagna, Commissione Regionale dei Dispositivi Medici: Le medicazioni avanzate per il trattamento delle ferite acute e croniche. Delibera Regionale n. 1523/2008. 2010.
6. Winter G. Formation of scab and rate of epithelialization of superficial wound in the skin of the young domestic pig. Nature, 1962.
7. Jones J. Winter's concept of moist wound healing: a review of the evidence and impact on clinical practice. J Wound Care. 2005 Jun;14(6):273–6.
8. Timmers MS, Le Cessie S, Banwell P, et al. The effects of varying degrees of pressure delivered by negative-pressure wound therapy on skin perfusion. Ann Plast Surg 2005; 55(6): 665–671; discussion 1097-98.
9. European Wound Management Association (EWMA). Position Document: Hard-to-heal wounds: a holistic approach. London: MEP Ltd, 2008.
10. Vowden K. Conservative management of pressure ulcers. In: Banwell PE, Harding K (eds.), *Vacuum Assisted Closure TM Therapy: Science and Practice*. London: MEP Ltd, 2006. 12.
11. Sumpio BE, Banes AJ, Link WG, et al. Enhanced collagen production by smooth muscle cells during repetitive mechanical stretching. Arch Surg. 1988;123(10):1233–6.
12. Ilizarov GA. Clinical application of the tension-stress effect for limb lengthening. Clin Orthop Relat Res. 1990;250:8–26.

13. Greene AK, Puder M, Roy R, et al. Microdeformational wound therapy: effects on angiogenesis and matrix metalloproteinases in chronic wounds of 3 debilitated patients. Ann Plast Surg. 2006;56(4):418–22.
14. Fabian TS, Kaufman HJ, Lett ED, et al. The evaluation of subatmospheric pressure and hyperbaric oxygen in ischemic full-thickness wound healing. Am Surg. 2000;66(12):1136–43.
15. Gustafsson RI, Sjögren J, Ingemansson R. Deep sternal wound infection: a sternal-sparing technique with vacuum-assisted closure therapy. Ann Thorac Surg 2003; 76(6): 2048–2053; discussion 2053.
16. Stechmiller JK, Kilapadi DV, Childress B, et al. Effect of vacuum-assisted closure therapy on the expression of cytokines and proteases in wound fluid of adults with pressure ulcers (letter to editor). Wound Rep Regen. 2006;14:371–4.
17. Sjögren J, Gustafsson R, Nilsson J, et al. Clinical outcome after poststernotomy mediastinitis: vacuum-assisted closure versus conventional therapy. Ann Thorac Surg. 2005;79(6):2049–55.
18. Cowan KN, Teague L, Sue SC, et al. Vacuum-assisted wound closure of deep sternal infections in high-risk patients after cardiac surgery. Ann Thorac Surg. 2005;80(6):2205–12.
19. Mehbod AA, Ogilvie JW, Pinto MR, et al. Postoperative deep wound infections in adults after spinal fusion: management with vacuum-assisted wound closure. J Spinal Disord Tech. 2005;18(1):14–7.
20. Dosluoglu HH, Schimpf DK, Schultz R, et al. Preservation of infected and exposed vascular grafts using vacuum assisted closure without muscle flap coverage. J Vasc Surg. 2005;42(5):989–92.
21. Schimp VL, Worley C, Brunello S, et al. Vacuum-assisted closure in the treatment of gynecologic oncology wound failures. Gynecol Oncol. 2004;92(2):586–91.
22. Cro C, George KJ, Donnelly J, et al. Vacuum assisted closure system in the management of enterocutaneous fistulae. Postgrad Med J. 2002;78:364–5.
23. Goverman J, Yelon JA, Platz JJ, et al. The 'fistula VAC,' a technique for management of enterocutaneous fistulae arising within the open abdomen: report of 5 cases. J Trauma 2006; 60(2): 428–431; discussion 431.
24. McCord SS, Naik-Mathuria BJ, Murphy KM, et al. Negative pressure therapy is effective to manage a variety of wounds in infants and children. Wound Repair Regen. 2007;15(3):296–301.
25. Chariker ME, Gerstle TL, Morrison CS. An algorithmic approach to the use of gauzebased negative-pressure wound therapy as a bridge to closure in pediatric extremity trauma. Plast Reconstr Surg. 2009;123(5):1510–20.
26. World Union of Wound Healing Societies (WUWHS). Principles of best practice: Vacuum assisted closure: recommendations for use. A consensus document. London: MEP Ltd, 2008.
27. Llanos S, Danilla S, Barraza C, et al. Effectiveness of negative pressure closure in the integration of split thickness skin grafts: a randomized, double-masked, controlled trial. Ann Surg. 2006;244(5):700–5.
28. Henderson V, Timmons J, Hurd T, Deroo K, Maloney S, Sabo S. NPWT in everyday practice Made Easy. Wounds International 2010; 1(5).
29. Awad T, Butcher M (2012) Managing diabetic foot ulceration with a new, highly portable NPWT device. Wounds International 3(2): 40–41.
30. Chen SZ, Li J, Li XY, et al. Effects of vacuum-assisted closure on wound microcirculation: an experimental study. Asian J Surg 2005; 28:211–17.
31. Ousey KJ, PhD, MA, PGDE, BA, RN, reader, School of Human and Health Sciences, Centre for Health and Social Care Research, University of Huddersfield, Queensgate, Huddersfield, West Yorkshire, United Kingdom.
32. EWMA Document: Negative Pressure Wound Therapy. Overview, challenges and perspectives. 2017.