Negative Pressure Wound Therapy in the Management of Pressure Ulcers

14

Valentina Dini, Salvatore Panduri, and Marco Romanelli

Introduction

Negative pressure wound therapy (NPWT) is defined as the controlled application of sub-atmospheric pressure across a wound to create an environment that promotes wound healing by secondary or tertiary (delayed primary) intention [1]. A suction pump provides continuous negative pressure that allows removal of fluid from the wound bed [1]. Some of the first studies using NPWT used "cupping" (with cup-shaped devices) as a way to remove toxins from wounds [2], which evolved into closed-suction treatment techniques that allowed for true sub-atmospheric pressure over the wound [3, 4].

In 1993, Fleischmann et al. [5] reported on their use of NPWT in 15 of their patients with open fractures. Drainage tubes were inserted into a polyvinyl foam and connected to a suction device to deliver negative pressure. A transparent polyurethane dressing also covered the foam. Their results showed improved healing with granulation tissue formation in all 15 patients [5].

The use of negative pressure generated by simple suction wall units or by portable suction units may have problems in terms of achievement, control and maintenance of desired levels of negative pressure. In 1997, the first commercialized NPWT system, developed by Argenta and Morykwas [6, 7], became available and was licensed to Kinetic Concepts, Inc. as VACUUM ASSISTED CLOSURE™ Therapy (V.A.C.® Therapy). The Food and Drug Administration (FDA) cleared the V.A.C.® Therapy System as a device that is intended to create an environment that promotes wound healing by secondary or tertiary (delayed primary) intention by preparing the wound bed for closure, reducing edema, promoting granulation tissue formation and perfusion, and by removing exudate and infectious material. The device is indicated for patients with chronic, acute, traumatic, subacute and dehisced

V. Dini · S. Panduri · M. Romanelli (✉)
Department of Dermatology, Santa Chiara Hospital, University of Pisa, Pisa, Italy

M. Romanelli et al. (eds.), *Science and Practice of Pressure Ulcer Management*,
https://doi.org/10.1007/978-1-4471-7413-4_14

Table 14.1 General indications for NPWT

1. Acute wounds
2. Chronic wounds
3. Traumatic wounds
4. Partial—thickness burns
5. Dehisced wounds
6. Diabetic ulcer
7. Pressure ulcer
8. Venous ulcer
9. Flaps
10. Grafts

Table 14.2 Contraindications for NPWT

1. Malignancy in the wound
2. Untreated osteomyelitis
3. Nonenteric and unexplored fistulas
4. Necrotic tissue with eschar present
5. Placement over exposed blood vessels, anastomotic sites, organs, or nerves

wounds, partial-thickness burns, ulcers (such as diabetic, pressure, or venous insufficiency), flaps, and grafts (Table 14.1). Table 14.2 lists the contraindications for NPWT.

The NPWT system consists of a reticulated open cell foam (ROCF) dressing, a pressure-sensing pad, evacuation tubing, a collection canister for fluid, and a computerized therapy unit with adjustable settings that generates negative pressure. The ROCF dressing is placed into the wound cavity and able to adapt to the shape of wound. The dressing is covered by a thin adhesive film, creating a closed system. After the wound is sealed, the evacuation tube is attached to an effluent connecting canister, and the canister is connected to the adjustable vacuum pump that generates a continuous or intermittent pressure ranging from −50 to −200 mmHg, depending on the nature of the wound [7].

Mechanisms of Action

The exact mechanisms of action of NPWT are unknown. Some hypotheses include: removal of excess fluid and improving wound bed circulation, reducing bacterial load, promoting cell proliferation and synthesis, increasing the level of angiogenic and stimulatory cytokines, and endothelial cell mobilization [8–15]. Furthermore, the ROCF dressing used with NPWT plays a key role in allowing a uniform distribution of pressure over the wound surface. To help promote healing, NPWT provides mechanical forces at the tissue level to create macrostrain and microstrain. Macrostrain causes the ROCF to contract under a controlled negative pressure setting, drawing the wound edges together, reducing the overall wound area and allowing for granulation tissue to fill in, leading to improved wound healing. Microstrain is the transduction of pressure to tissue surfaces, resulting in cell surface deformation as the tissue is being pulled up into the pores (tissue stretch) and the

compression of tissue at the struts. This microstrain leads to cellular proliferation, which promotes granulation tissue formation [16–19]. These effects, as predicated by the adequate delivery of negative pressure to the wound site, are translated into clinical outcomes such as improved tissue perfusion [20], reduced tissue edema [21], and increased granulation tissue formation [22]. The scientific foundation for NPWT forms the basis for the improved patient outcomes observed in the published clinical literature and supports its use for temporizing wounds and protecting them from external contamination during long-term care.

Recently, other dressings, such as medical gauze, have been used with NPWT. One study reported that NPWT with gauze showed similar reductions in wound volume compared to published data from foam-based systems [23]. Both ROCF and gauze dressings are currently used with NPWT for the treatment of wounds and promote healing by by providing a moist wound environment and acting on the removal of exudates. However, due to the differences in dressing interactions, gauze may not offer the same level of granulation tissue formation that is affected through macrostrain and microstrain with ROCF dressings [6, 16–19].

NPWT Guidelines for the Management of Pressure Ulcers

A consensus panel of experienced wound care practitioners initially met in 2004 to develop an algorithm to assist physicians and clinicians regarding the use of NPWT in pressure ulcer treatment [24]. Two years later, another consensus panel met to expand upon the 2004 guidelines and further define the treatment algorithms for integrating the use of NPWT in patients with Stage III and Stage IV pressure ulcers [25]. Additionally, other guidelines exist for the use of NPWT in pressure ulcer management [26, 27].

NPWT should be used in full-thickness skin defects: Stage III and Stage IV pressure ulcers (Fig. 14.1a–c). The dimension of the wound should be enough to allow an adequate contact between the ROCF dressing and wound bed and for safe removal of the ROCF. The decision to use NPWT is not necessarily determined by the depth of wound. Notably, NPWT may be used in either shallow or deep pressure ulcers, when the granulation tissue is poor or inadequate, and when there is a heavy exudate. NPWT can also be used with wounds that have undermining or tunneling. In addition to the contraindications listed in Table 14.2, the initial 2004 consensus panel established that the following wound characteristics would not be appropriate for NPWT use: wounds with inadequate beds, small wounds that do not allow the ROCF dressing to come in direct contact with the wound bed, freshly debrided wounds without adequate hemostasis, wounds with eschar, wounds with inadequate circulation, fibrotic wounds, and desiccated wounds [24].

Furthermore, NPWT must be used in pressure ulcers free of necrotic tissue; therefore, NPWT should begin after debridement. NPWT can be applied only in appropriate patients and should not be used with the following patient:

- untreated malnutrition
- patients who cannot tolerate pain that may be caused by NPWT treatment

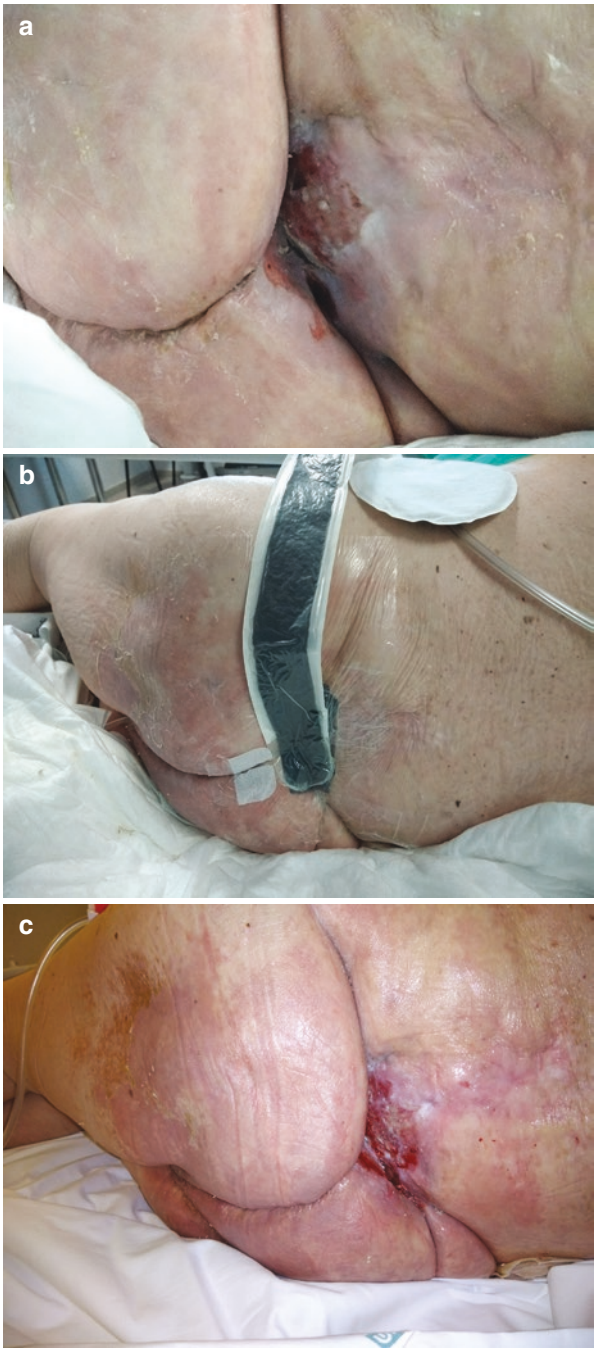

Fig. 14.1 Stage 3 pressure ulcer in the sacral area (**a**) before application, (**b**) with NPWT and (**c**) after 2 weeks of NPWT

- allergy or tissue intolerance to the adhesive in the drape used to seal the foam dressing
- patients who are unable to adhere to the treatment protocol
- patients with conditions as uncontainable incontinence, hyperhidrosis or certain anatomic characteristics (e.g., creases or folds in body tissue) that make impossible to achieve a seal
- patients with bleeding disorders (e.g., platelet disfunction)

Pressure ulcers managed with NPWT should be monitored at every dressing change [28]. Generally, dressing changes can be done every 48 h and can be extended up to 72 h (3 times a week), but in the presence of infection, the dressing change should be done every 12–24 h. Ultimately, dressing changes intervals should be based on manufacturer guidelines and clinician discretion.

Optimal negative pressure levels are not well established, but the typical range is between −75 and −125 mmHg. The optimal setting of NPWT in pressure ulcer is −125 mmHg using the black foam and − 125 to −175 mmHg using the white foam. In the case of pain, the pressure can be reduced in −25 mmHg intervals, with a minimum pressure level of −75 mmHg. In a patient who is of advanced age, emaciated, or taking an anticoagulant such as warfarin, the initial baseline pressure of −75 or − 100 mmHg is recommended. If these pressure levels are tolerated, it is possible to increase the pressure to up to −125 mmHg. Continuous negative pressure mode should be used for the first 48 h of treatment and can then be switched to intermittent negative pressure mode (5 min on, 2 min off) for the remainder of therapy [29]. In certain wound conditions, it is necessary to utilize the continuous negative pressure mode longer than 48 h or even for the duration of therapy. The patients or the conditions, in which the use of NPWT using the continuous mode longer than 48 h or for the duration of therapy are:

- discomfort with the use of intermittent mode
- anatomic issue (e.g., creases or folds in the skin) or wounds in difficult areas (e.g., perineal or toe wounds) that make difficult to maintain an airtight seal
- wounds with undermined areas or tunneling (in these wounds, the continuous negative pressure modes helps in the closure of the ulcer)
- wounds with heavy drainage after 48 h

The black foam could be used to stimulate granulation tissue while assisting in wound contraction. The utilization of white foam dressing is more appropriate for epithelialization, for protection of structure, for control of granulation tissue growth into the foam, for tunneled or undermined areas, and for patients who cannot tolerate the black foam due to the pain.

If the patient feels pain, the following are some strategies to reduce pain:

- switch from the black foam dressing to the white foam dressing
- use the continuous negative pressure mode in place of intermittent mode
- interpose a non-adherent meshed interface between the wound and the foam dressing
- use a protection skin product around the dermal wound margin
- use appropriate topical anesthetics or systemic analgesics
- moisten the foam dressing before removal

NPWT can be discontinued when the patient's wound is ready for a skin graft. If wounds do not progress or become worse, surgical reconstruction of the pressure ulcer may be necessary or another adjunctive modality can be used. NPWT can be used to help with the healing of flaps and to decrease the volume of the wound until the ulcer is superficial, using another dressing that can achieve a stable reepithelization. If after 2–4 weeks the pressure ulcer does not improve or deteriorates, the clinicians must evaluate the appropriateness of NPWT.

Evidence on NPWT

Deva et al. [30] have shown that NPWT reduces the depth of pressure ulcers when compared to traditional forms of topical therapies [30]. This result is supported by a randomized clinical trial (RCT) by Joseph et al. [31] who reported that compared to wet-to-moist dressings, NPWT had a significantly higher percent change in pressure ulcer depth, width, and volume [31]. In contrast, a prospective randomized trial by Wanner et al. [32] found no significant difference between NPWT and wet-to-dry dressing in time-to-reach a 50% reduction of wound volume and formation of granulation tissue [32]. Nevertheless, a comparative retrospective study of 281 patients with pressure ulcers showed significantly better wound response, satisfactory wound closure, and time-to-reach closure with NPWT versus alginate or hydrocolloid dressing [33]. In a RCT comparing the efficiency of NPWT (n = 5) or redon drain (n = 5) to assist wound healing of stage III/IV pressure ulcers, Wild et al. [34] reported that the automated NPWT system provided significantly superior support. After an average of 8.5 days of treatment, the NPWT mean percent of granulation coverage of the wound bed was 60% higher than that of the redon drain group. Whereas the NPWT group showed a 27% reduction in fibrin tissue at the wound base, the redon group showed a 22% increase. Despite an initial plan to include 17 patients in each group, the study was terminated early due to the drastic difference in outcome. Additionally, NPWT required fewer dressing changes and was better equipped to maintain a steady negative pressure without leakage [34].

In 2011, de Laat et al. evaluated the reduction of wound volume using NPWT versus sodium hypochlorite dressings [35]. This study demonstrated a 50% reduction in the median treatment time in the NPWT group compared to group of patients treated with sodium hypochlorite dressing. Several studies have supported the use of

NPWT in conjunction with systemic antibiotics to treat patients with infected pressure ulcers. Isago et al. [36] reported a consistent reduction in wound depth and surface area after NPWT treatment of 10 patients with stage IV chronic pressure ulcers (mean 61.2% and 55.1 reduction, respectively) [36]. All wounds tested positive for bacterial contamination prior to treatment, and although only 3 wounds were deemed microbiologically clean after 4–7 weeks of treatment, all had substantially reduced in size. In a RCT comparing NPWT to a hydrogel wound dressing, the NPWT group had a higher percent reduction in ulcer volume and a decreased proliferation of inflammatory cells [37]. Ulcers treated with NPWT also exhibited improvement despite the presence of underlying osteomyelitis. A study by Yao et al. (2014) [38] that included patients with different ulcers of the lower extremity (diabetic foot ulcers, arterial ulcers, venous insufficiency ulcer and pressure ulcers) reported a greater healing rate in group of NPWT compared the control group.

Recently, NPWT with instillation and a dwell time (NPWTi-d; V.A.C. VERAFLO™ Therapy, KCI, an Acelity Company, San Antonio, TX) using an ROCF dressing with through holes (ROCF-CC; V.A.C. VERAFLO CLEANSE CHOICE DRESSING; KCI, an Acelity Company, San Antonio, TX) has been used in the management of pressure ulcers [39, 40]. Teot et al. [39] described their experience using NPWTi-d with ROCF-CC in patients with complex wounds, including pressure ulcers, that had viscous wound exudate and areas of devitalized tissue. Results showed that after 3 days of adjunctive use of NPWTi-d with ROCF-CC, the majority of the thick exudate and slough was removed from the during therapy [39]/ Fernandez et al. [40] reported on their initial experience using NPWTi-d with ROCF-cc in 5 pressure ulcer patients. The authors concluded that NPWTi-d with ROCF-CC "provided effective and rapid removal of thick exudate and infectious materials and promoted excellent development of underlying granulation tissue" [40]. Additional studies should be performed on larger patient populations to determine the efficacy of this therapy for pressure ulcer management.

Economic Impact

Pressure ulcers are a serious health issue and can have a significant economic impact. The major cost drivers for wound care include time to healing, staff time, hospital stay, number of dressings, rate of infections and long waiting time from diagnosis to treatment [41]. Only a small portion of costs involve technical requirements to treat the wound. For instance, the cost of materials (e.g., dressings) typically accounts for 10–20% of the total cost of treating a patient [41, 42]. An initial study by Philbeck et al. [43] examined the cost effectiveness of NPWT as compared to standard therapy based on the total cost to heal a pressure ulcer of size. The authors found that it would take 97 days and cost $14.456 to heal a typical 22.2 cm^2 trunk or trochanter wound with NPWT compared to 247 days and a cost of $23,465 to heal the same size wound using standard therapy (i.e., saline-soaked gauze; based on the outcomes of Ferrel et al.) [44]. Multiple studies have suggested that use of NPWT for pressure ulcers may shorten the length of care and reduce healthcare

costs. A comparative retrospective study demonstrated that pressure ulcer patients treated with NPWT experienced lower rates of hospitalization and emergent care encounters compared to other treatment plans, providing an estimated cost savings of $4209 per episode [45]. Research has also emerged indicating that early implementation is important to receive the full benefit of NPWT. In a retrospective analysis of 98 Stage III/IV pressure ulcer patients, the median length of home health agency (HHA) stay in the NPWT early initiation (within 30 days of start of HHA care) group was 85 days, as opposed to the 166-day median length of stay for the late initiation (longer than 30 days after start of HHA care) group. A greater percentage of patients in the early adoption group (42%) were discharged from home care during their first episode versus 3% in the late group. After controlling for patient demographic variables, regression analysis indicated that for each day NPWT was delayed, almost 1 day was added to the total length of stay [46]. Larger randomized studies are necessary to determine the cost effectiveness of NPWT compared to other wound therapies for the treatment of pressure ulcers.

Conclusions

The literature suggests that NPWT is a valid option for the management of Stage III and IV pressure ulcers, but it is important to note that pressure ulcers require a multimodal approach. Rhee et al. [47] have performed a systematic review to evaluate the efficacy and safety of NPWT for the treatment of chronic wounds in the home setting. Although the authors found a paucity of well-designed and well-conducted studies, they concluded that "standardization of wound care research protocols, such as providing consistency in comparator groups, robust randomized study designs, larger trials, and common definitions of outcomes, would be helpful in providing evidence to inform decisions about the use of NPWT" [47]. In conclusion, further randomized clinical studies will be important to evaluate the efficacy and safety of NPWT in pressure ulcers.

References

1. Banwell P, Musgrave M. Topical negative pressure (TNP) therapy: mechanisms and indications. In: Banwell P, Teot L, editors. 1st International Topical Negative Pressure (TNP) Therapy Focus Group Meeting, Proceedings London, UK 2003. London: European Tissure Repair Society; 2003. p. 73–88.
2. Porter R. Surgery. In: Porter R, editor. Blood and guts: a short history of medicine. 1st ed. London: Allen Lane/Penguin Books; 2002. p. 109–34.
3. Fox JW, Golden GT. The use of drains in subcutaneous surgical procedures. Am J Surg. 1976;132:673–4.
4. Fay MF. Drainage systems. Their role in wound healing. AORN J. 1987;46:442–55.
5. Fleischmann W, Strecker W, Bombelli M, Kinzl L. Vacuum sealing as treatment of soft tissue damage in open fractures. Unfallchirurg. 1993;96:488–92.
6. Argenta LC, Morykwas MJ. Vacuum-assisted closure: a new method for wound control and treatment: clinical experience. Ann Plast Surg. 1997;38:563–76.
7. Morykwas MJ, Argenta LC, Shelton-Brown EI, McGuirt W. Vacuum-assisted closure: a new method for wound control and treatment: animal studies and basic foundation. Ann Plast Surg. 1997;38:553–62.

8. Niezgoda JA, Mendez-Eastman S. The effective management of pressure ulcers. Adv Skin Wound Care. 2006;19:3–15.
9. Plikaitis CM, Molnar JA. Subatmospheric pressure wound therapy and the vacuum-assisted closure device: basic science and current clinical successes. Expert Rev Med Devices. 2006;3:175–84.
10. Schintler MV. Negative pressure therapy: theory and practice. Diabetes Metab Res Rev. 2012;28:72–7.
11. Scherer SS, Pietramaggiori G, Mathews JC, Prsa MJ, Huang S, Orgill DP. The mechanism of action of the vacuum-assisted closure device. Plast Reconstr Surg. 2008;122:786–97.
12. Erba P, Ogawa R, Ackermann M, et al. Angiogenesis in wounds treated by microdeformational wound therapy. Ann Surg. 2011;253:402–9.
13. Seo SG, Yeo JH, Kim JH, Kim JB, Cho TJ, Lee DY. Negative-pressure wound therapy induces endothelial progenitor cell mobilization in diabetic patients with foot infection or skin defects. Exp Mol Med. 2013;45:e62.
14. Orgill DP, Manders EK, Sumpio BE, et al. The mechanisms of action of vacuum assisted closure: more to learn. Surgery. 2009;146:40–51.
15. Lu F, Ogawa R, Nguyen DT, et al. Microdeformation of three-dimensional cultured fibroblasts induces gene expression and morphological changes. Ann Plast Surg. 2011;66:296–300.
16. Saxena V, Hwang CW, Huang S, Eichbaum Q, Ingber D, Orgill DP. Vacuum-assisted closure: microdeformations of wounds and cell proliferation. Plast Reconstr Surg. 2004;114:1086–96.
17. McNulty AK, Schmidt M, Feeley T, Kieswetter K. Effects of negative pressure wound therapy on fibroblast viability, chemotactic signaling, and proliferation in a provisional wound (fibrin) matrix. Wound Repair Regen. 2007;15:838–46.
18. McNulty AK, Schmidt M, Feeley T, Villanueva P, Kieswetter K. Effects of negative pressure wound therapy on cellular energetics in fibroblasts grown in a provisional wound (fibrin) matrix. Wound Repair Regen. 2009;17:192–9.
19. Morykwas MJ, Simpson J, Punger K, Argenta A, Kremers L, Argenta J. Vacuum-assisted closure: state of basic research and physiologic foundation. Plast Reconstr Surg. 2006;117:121S–6S.
20. Wackenfors A, Sjogren J, Algotsson L, Gustafsson R, Ingemansson R, Malmsjo M. The effect of vacuum-assisted closure therapy on the pig femoral artery vasomotor responses. Wound Repair Regen. 2004;12:244–51.
21. Kamolz LP, Andel H, Haslik W, Winter W, Meissl G, Frey M. Use of subatmospheric pressure therapy to prevent burn wound progression in human: first experiences. Burns. 2004;30:253–8.
22. Blume PA, Walters J, Payne W, Ayala J, Lantis J. Comparison of negative pressure wound therapy using vacuum-assisted closure with advanced moist wound therapy in the treatment of diabetic foot ulcers: a multicenter randomized controlled trial. Diabetes Care. 2008;31:631–6.
23. Campbell PE, Smith GS, Smith JM. Retrospective clinical evaluation of gauze-based negative pressure wound therapy. Int Wound J. 2008;5:280–6.
24. Gupta S, Baharestani M, Baranoski S, et al. Guidelines for managing pressure ulcers with negative pressure wound therapy. Adv Skin Wound Care. 2004;17:1–16.
25. Baharestani M, de Leon J, Mendez-Eastman S, et al. Consensus statement: a practical guide for managing pressure ulcers with negative pressure wound therapy utilizing vacuum-assisted closure- understanding the treatment algorithm. Adv Skin Wound Care. 2008;21:1–20.
26. Whitney J, Phillips L, Aslam R, et al. Guidelines for the treatment of pressure ulcers. Wound Repair Regen. 2006;14:663–79.
27. National Pressure Ulcer Advisory Panel, European Pressure Ulcer Advisory Panel, Pan Pacific Pressure Injury Alliance. Prevention and treatment of pressure ulcers: quick reference guide. In: Haesler E, editor. Perth: Cambridge Media; 2014. p. 1–72. Ref Type: Report.
28. Wound Ostomy and Continence Nurses Society (WOCN). Guideline for prevention and management of pressure ulcers. 2. 1-1-2003. Glenview: Wound, Ostomy and Continence Nurses Society. WOCN Clinical Practice Guideline Series. Ref Type: Report.
29. V.A.C. Therapy Clinical Guidelines: a reference source for clinicians. 2004. San Antonio: Kinetic Concepts, Inc. Ref Type: Pamphlet.

30. Deva AK, Buckland GH, Fisher E, et al. Topical negative pressure in wound management. Med J Aust. 2000;173:128–31.
31. Joseph E, Hamori CA, Bergman S, Roaf E, Swann NF, Anastasi GW. A prospective, randomized trial of vacuum-assisted closure versus standard therapy of chronic nonhealing wounds. Wounds. 2000;12:60–7.
32. Wanner MB, Schwarzl F, Strub B, Zaech GA, Pierer G. Vacuum-assisted wound closure for cheaper and more comfortable healing of pressure sores: a prospective study. Scand J Plast Reconstr Surg Hand Surg. 2003;37:28–33.
33. Smith N. The benefits of VAC therapy in the management of pressure ulcers. Br J Nurs. 2004;13:1359–65.
34. Wild T, Stremitzer S, Hoelzenbein T, Ludwig C, Ohrenberger G. Definition of efficiency in vacuum therapy-a randomized controlled trial comparing Redon drains with V.A.C. Therapy. Int Wound J. 2008;5:641–7.
35. de Laat EH, van den Boogaard M, Spauwen PH, van Kuppevelt DH, van Goor H, Schoonhoven L. Faster wound healing with topical negative pressure therapy in difficult-to-heal wounds: a prospective randomized controlled trial. Ann Plast Surg. 2011;67:626–31.
36. Isago T, Nozaki M, Kikuchi Y, Honda T, Nakazawa H. Negative-pressure dressings in the treatment of pressure ulcers. J Dermatol. 2003;30:299–305.
37. Ford CN, Reinhard ER, Yeh D, et al. Interim analysis of a prospective, randomized trial of vacuum-assisted closure versus the healthpoint system in the management of pressure ulcers. Ann Plast Surg. 2002;49:55–61.
38. Yao M, Fabbi M, Hayashi H, et al. A retrospective cohort study evaluating efficacy in high-risk patients with chronic lower extremity ulcers treated with negative pressure wound therapy. Int Wound J. 2014;11:483–8.
39. Teot L, Boissiere F, Fluieraru S. Novel foam dressing using negative pressure wound therapy with instillation to remove thick exudate. Int Wound J. 2017;14:842–8.
40. Fernandez L, Ellman C, Jackson P. Initial experience using a novel reticulated open cell foam dressing with through holes during negative pressure wound therapy with instillation for management of pressure ulcers. J Trauma Treat. 2017;6(5):410.
41. Jencks SF, Williams MV, Coleman EA. Rehospitalizations among patients in the Medicare fee-for-service program. N Engl J Med. 2009;360:1418–28.
42. Centers for Medicare and Medicaid Services (CMS). MedCAC Meetings 3/29/2005—Usual care of chronic wounds. 3-29-2005. Baltimore: Centers for Medicare and Medicaid Services. Ref Type: Report.
43. Philbeck TE, Whittington KT, Millsap MH, Briones RB, Wight DG, Schroeder WJ. The clinical and cost effectiveness of externally applied negative pressure wound therapy in the treatment of wounds in home healthcare Medicare patients. Ostomy Wound Manage. 1999;45:41–50.
44. Ferrell BA, Osterweil D, Christenson P. A randomized trial of low-air-loss beds for treatment of pressure ulcers. J Am Med Assoc. 1993;269:494–7.
45. Schwien T, Gilbert J, Lang C. Pressure ulcer prevalence and the role of negative pressure wound therapy in home health quality outcomes. Ostomy Wound Manage. 2005;51:47–60.
46. Baharestani MM, Houliston-Otto DB, Barnes S. Early versus late initiation of negative pressure wound therapy: examining the impact on home care length of stay. Ostomy Wound Manage. 2008;54:48–53.
47. Rhee SM, Valle MF, Wilson LM, Lazarus G, Zenilman JM, Robinson KA. Negative pressure wound therapy technologies for chronic wound care in the home setting: a systematic review. Wound Repair Regen. 2015;23:506–17.