Soft Tissue Management in Open Fractures of the Lower Leg: The Role of Vacuum Therapy

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Abstract

The management of severe open fractures of the lower leg continues to challenge the treating surgeon. Major difficulties include high infection rates as well as adequate temporary soft tissue coverage. In the past, these injuries were commonly associated with loss of the extremity. Today, vacuum therapy provides not only safe temporary wound coverage but also conditioning of the soft tissues until definitive wound closure. Amongst other advantages, bacterial clearance and increased formation of granulation tissue are attributed to vacuum therapy, making it an extremely attractive tool in the field of wound healing. However, despite its clinical significance, which is underlined by a constantly increasing range of indications, there is a substantial lack of basic research and well-designed studies documenting the superiority of vacuum therapy compared to alternative wound dressings. Vacuum therapy has been approved as an adjunct in the treatment of severe open fractures of the lower leg, complementing repeated surgical debridement and soft tissue coverage by microvascular flaps, which are still crucial in the treatment of these limb-threatening injuries. Vacuum therapy has in general proven useful in the management of soft tissue injuries and, since it is generally well tolerated and has low complication rates, it is fast becoming the gold standard for temporary wound coverage in the treatment of severe open fractures of the lower leg.

Key Words

Vacuum therapy · Factures · Lower limb injuries · Soft tissue injuries and infection · Wound healing

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Introduction

The management of severe open fractures of the lower leg remains a major challenge in surgery, and adequate treatment of the concomitant soft tissue injury is of the highest priority, since it determines the fate and outcome of bone and extremity [1, 2]. In the past, open wound treatment of fractures or osteosynthesis followed by flap coverage was often associated with loss of the extremity [3]. Additionally, higher complication rates relating to microvascular flap loss and infections hindered delayed reconstruction.

A variety of methods of temporary wound coverage before definitive wound closure have been described; nowadays, vacuum-assisted closure (VAC™, Kinetic Concepts, Inc., San Antonio, TX, USA) therapy (VT) can be regarded as the wound care modality in routine clinical use.

Simultaneously developed in the USA and Germany in the late 1980s, VT has gained increasingly widespread use over the past years, and the apparent clinical significance of VT is underlined by a continuously increasing range of indications in all surgical and medical fields [4, 5]. Within this trend, multiple reports have been published on the use of VT in open fractures [2, 6, 7]. However, it must be stated that, despite the widespread use of VT in the management of open fractures and beyond, there is still a lack of solid evidence in the literature on the superiority of VT compared to alternative wound dressings, and the exact

underlying mechanisms that lead to this apparent improved wound healing remain largely unknown [4].

The aim of this review is to present the current role and rationale of VT in the management of open fractures of the lower leg. Besides general historical development and physiological/pathophysiological mechanisms of VT, further consideration was given to indications, contraindications, and complications of VT in the management of these limb-threatening injuries, based on the current literature and personal experience.

Short History and Current Spectrum of Clinical Use of Vacuum Therapy

For a long time, the application of negative pressure has been a well-known surgical treatment option. Originally, it was described as an alternative to pressure dressings after radical mastectomy with the goal of preventing serum collection and rapid tissue adaptation [8].

In the early 1990s, Fleischmann et al. [6] reported on a novel technique of soft tissue management in open fractures using drainage tubes inserted into polyvinyl foam, transparent polyurethane dressing impermeable to bacteria, and vacuum bottles to produce negative pressure. The term ''vacuum sealing'' was established. In the mid-1990s, Argenta & Morykwas [9, 10] further assessed the physiological mechanisms of vacuum therapy in clinical and experimental studies. This led to the development and patenting of the vacuum-assisted closure device (VAC™, Kinetic Concepts Inc., San Antonio, TX, USA). In contrast to the latter, the resulting and currently used term ''VAC™ therapy'' (VT) describes a dynamic and controllable therapeutic system including variable treatment parameters, as described below.

The option of temporary closure of soft tissue defects using a simple technique was found to be very attractive to a variety of clinicians. This led not only to the widespread use of VT but also to the present discrepancy between a broad range of clinical indications based on reports of personal experience and cases as well as other forms of non-peer-reviewed literature and the lack of knowledge of the physiological mechanisms of VT [4, 5, 11].

The first experiences with VT comparable to the system used today were gained in the late 1980s and reported in the early 1990s. In these, acute and septic wounds were treated with this method [12–14], and shortly afterwards chronic wounds such as crural ulcers and decubitus ulcers were also treated [15]. There are now a wide range of indications [4, 5, 11]. Severe dermatological wounds as well as problematic wounds in vascular surgery are treated by VT [16, 17]. Plastic and reconstructive surgery has expanded its use of VT, as burns of the hand and fixation of skin grafts in particular have been shown to be ideal indications for VT [18, 19]. In trauma and orthopedic surgery, the range of indications has been extended to implant infections in endoprosthetics and spinal surgery [20]. In visceral surgery, entero- and lymphocutaneous fistulas as well as open abdomens are treated with VT [21, 22]. Furthermore, VT is used not only for wounds and soft tissue defects on the body surface but also for pathologies in the body cavity, such as bronchial stump insufficiency or pancreatic trauma [23, 24].

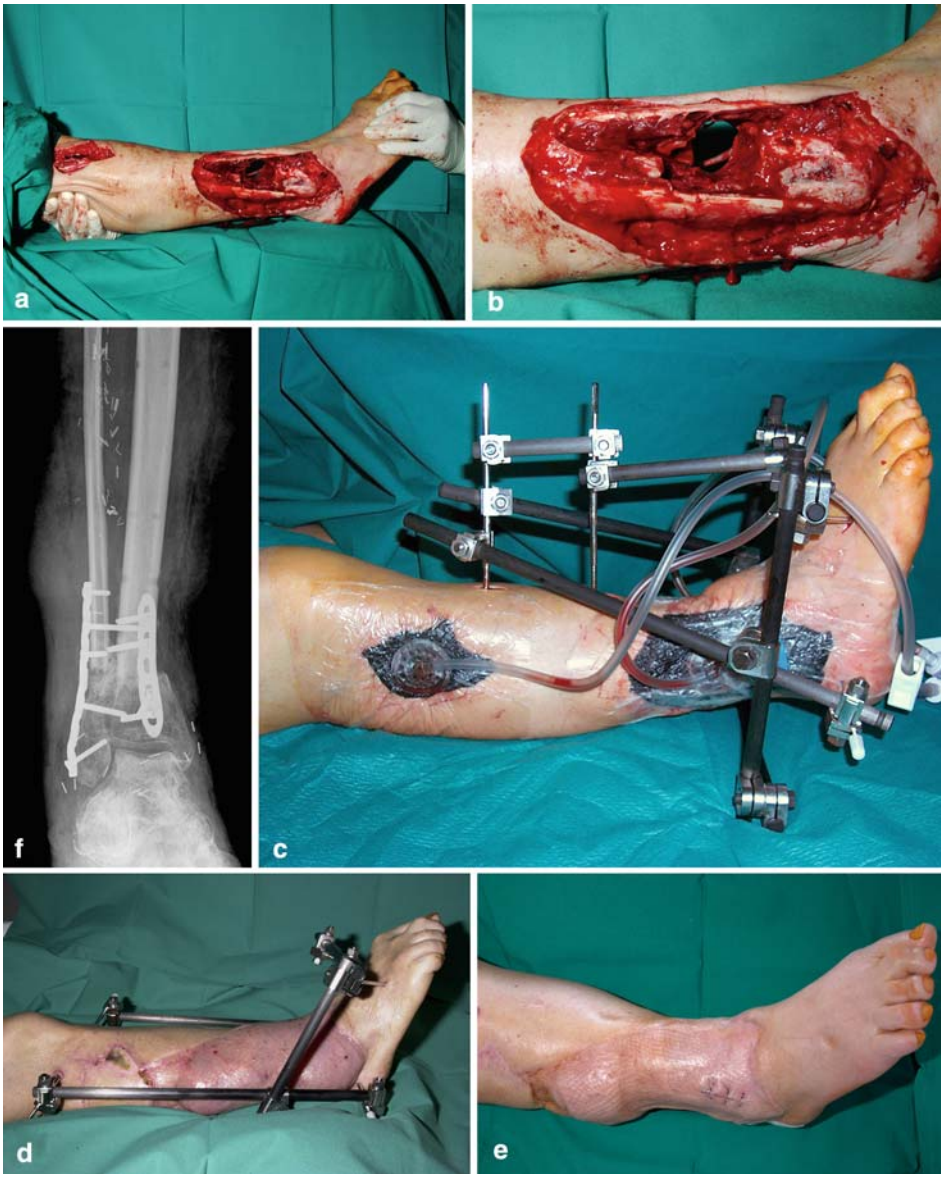
Concept and Mechanism of Vacuum Therapy

Principle of Application

The vacuum-assisted closure (VAC™, Kinetic Concepts, Inc., San Antonio, TX, USA) system is available commercially. Principally, it consists of a polyurethane ether foam sponge which is cut to fit directly over the wound surface. The adhesive dressing is trimmed and placed over the sponge to fix it in place. In addition, the sponge may be secured to the wound edges using skin staples or sutures. A small opening is then cut into the adhesive dressing over the sponge. An evacuation tube with a fenestrated distal end surrounded by an adhesive dressing is then attached over that opening. The fenestration at the end of the tube establishes communication between the lumen of the tube and the foam sponge. The proximal end of the evacuation tube is then connected via a drainage canister to an adjustable vacuum pump. The pump creates suction that allows subatmospheric pressure to be applied to the entire wound surface. The foam sponge enables equal distribution of the applied suction to the entire surface of the wound. The drainage canister collects any fluid that is extracted from the wound. The subatmospheric pressure can be applied continuously or intermittently with negative pressure up to 125 mmHg. Slight variations of the device based on this principle are now available for different ranges of applications. Figure 1 shows a clinical example of a patient with an open fracture of the lower leg treated by VT.

Specific Mechanisms of Vacuum Therapy

The subatmospheric pressure generated by VT has been shown to have several effects on the wound surface, leading to alteration of the physiological and chemical milieu. Morykwas et al. [10] showed in a pig



Figures 1a to 1d. Clinical case of vacuum therapy (VT) for severe open fracture of the lower leg. A 60-year-old polytraumatized female patient presented with a severe open fracture of the lower leg. Initial debridement and "second look" operations resulted in a large soft tissue and bony defect (a, b). The fracture was initially stabilized with external fixation and VT was applied to the soft tissue defect for temporary coverage and conditioning (c). Plate osteosynthesis of the tibia and fibula was performed on day 6 and definitive wound closure was performed using a free latissimus dorsi microvascular flap on day 8. Later on, the external fixation was removed after four weeks (d), and finally autologous bone grafting was performed after 6 weeks (e, f).

model that both intermittent as well as continuous subatmospheric pressure increased granulation tissue formation compared with control wounds.

The first mechanisms postulated for this increased granulation tissue formation and wound response was the resultant increase in local blood flow, which was shown to be up to fourfold in this study.

The second mechanism assumed to contribute to the observed granulation tissue formation was the mechanical stress applied by VT to the wound surface, as experimental studies have previously shown that mechanical stress can induce tissue responses, including cytokine release and cell proliferation [25–27]. It was also shown that application of subatmospheric pressure alters the cytoskeleton of the cells in the wound bed [28]. This alteration then disrupts the integrin bridges of the cytoskeleton, triggering the release of intracellular secondary messengers, which in turn upregulate cell proliferation. Hence, the increased rate of granulation tissue formation may be attributed to this release of secondary messengers.

As local cellular and humoral components play an important role during each phase of wound healing [29], it can further be hypothesized that VT may cause mechanically triggered immunomodulation as well as neovascularization and/or angiogenesis. This was

corroborated by an initial study of our own group demonstrating significantly increased levels of proinflammatory cytokines and growth factors in wound fluids during VT as compared to alternative Epigard™ dressing used as temporary wound coverage in a total of 21 patients presenting with traumatic wounds [30]. Based on these results, the possible impact of VT on local inflammation and neovascularization was further assessed. In a more recent study including a total of 32 patients with traumatic wounds, our own group showed not only significantly higher interleukin (IL)-8 and vascular endothelial growth factor (VEGF) levels in wound fluids during VT compared to alternative Epigard™ dressings, but also increased neovascularization by CD31 and von Willebrand factor immunohistochemistry in wound biopsies. Additionally, there was an accumulation of neutrophils and augmented expression of VEGF in wound biopsies during VT [31]. These results demonstrated for the first time that there is a selective and locally amplified humoral and cellular immune reaction as well as accelerated neovascularization during VT, suggesting that VT leads to increased local IL-8 and VEGF concentrations, which may trigger accumulation of neutrophils and angiogenesis, thus accelerating neovascularization.

The third mechanism hypothesized to contribute to the increased rate of granulation tissue formation during VT is the effect of continuous suction on the removal of inhibitory factors. Shi et al. [32] showed a marked decrease of MMP-1-, MMP-2- as well as MMP-13-mRNA during VT, meaning that removal of these metalloproteases allows local growth factors to function more efficiently.

Finally, Morykwas et al. [10] showed that VT decreases the bacterial count of infected wounds to levels that would allow for spontaneous healing within 4–5 days. Bacterial infection has been shown to alter the physiological healing process by not only disrupting and prolonging the inflammatory phase of wound healing but also inhibiting the function of leukocytes and the formation of granulation tissue [33]. The ability of VT to decrease local bacterial count can be attributed to the three properties of increased blood flow, decreased interstitial edema, and removal of harmful enzymes from the wound [5].

Indications for Vacuum Therapy

The VT device can be applied to any type of tissue or material, including soft tissues such as dermis, fat, fascia, tendon, muscle and blood vessels, as well as bone, synthetic mesh and hardware [5, 11]. The two most important prerequisites are, on the one hand, proper wound debridement to avoid the risk of promoting a deeper or systemic infection and, on the other hand, well-vascularized soft tissue, as further necrosis is likely to occur at the wound edges if VT is applied to an ischemic wound.

VT has greatly simplified wound management. It is currently well accepted and widely used as an initial dressing after wound debridement due to its abovementioned properties of reducing wound edema, controlling local bacterial growth and promoting granulation tissue formation. Altogether, VT provides a safe temporary wound environment, allowing reconstructive surgery and definitive wound closure to be planned electively rather than preformed urgently. In addition, there are several clinical studies which indicate that the application of VT allows a less complex mode of definitive wound closure, such as wound healing by secondary intention or a simple split skin graft rather than by microsurgical free flaps, to be chosen [34, 35]. Furthermore, VT ideally prepares wounds that are to be closed by delayed primary closure or with a local flap again by decreasing wound edema and wound size and therefore facilitating mobilization of the skin edges and reducing tension when rotating or advancing a flap. For split skin grafts, VT is both an excellent modality for stimulating the wound to develop an adequate bed of granulation for the graft and an ideal dressing for ensuring excellent skin graft take [36].

Complications and Contraindications of Vacuum Therapy

Generally, complications associated with VT are rare and of low morbidity. However, serious events have been reported initially, such as toxic shock syndrome or enteric fistula [9, 37]. These were mostly related to inadequate technique, incorrect application and management. In addition, hemodynamic instability is another potential complication of VT, as large volumes of fluid may be extracted from the wound depending on the type, size and location of the wound. Less serious complications associated with VT are pain, skin irritation or maceration, pressure from the tubing, odor, tissue necrosis, bleeding or infection. These affect up to 25% of patients during VT and can be avoided through the use of the proper technique and appropriate management and patient selection [5, 11].

Accordingly, there are a few contraindications to VT that are described in the literature, which have been corroborated by our personal experiences [5, 11]. They can be exclusively derived from the above complications and include for example fragile, damageable

skin and ischemic tissue as well as the presence of malignancy [28]. VT should not be used in patients with thin and sensitive skin due to age or chronic corticosteroid use, as the skin may be sheared or avulsed upon the removal of the adhesive tape during dressing change. In open fractures, therefore, we prefer to protect surrounding superficial skin abrasions and contused or damaged wound edges that are not debrided and are going to be observed for further demarcation using hydrocolloid dressings, such as Comfeel Plus™ transparent dressing (Coloplast, Coloplast AG, Euro Business Center, Blegistrasse 1, CH-6343 Rotkreuz, Switzerland). Similarly, ischemic wounds may develop further skin necrosis at the wound edges and so do not qualify for VT until revascularization. Finally, VT is contraindicated in patients with neoplasm, as further tumor growth may be stimulated by the mechanical stretching that occurs during VT [25–27].

Vacuum Therapy in Open Fractures of the Lower Leg

The management of high-energy open fractures continues to be a difficult problem confronting the surgeon involved in the treatment of these injuries. Open fractures have high incidences of malunion and infection, especially when they involve the tibia [1, 38, 39]. Adequate treatment of the concomitant soft tissue injury is of the highest priority, since it determines the fate and outcome of bone and extremity. The essential part of an initial soft-tissue damage treatment is copious irrigation and thorough debridement, which can cause significant soft-tissue defects that demand temporary wound coverage followed by secondary wound closure or reconstructive surgery [3, 40]. Various surgical methods are available in this regard, mainly including skin grafts, local flaps or free flap transfers [1].

If possible, the goal is to close open wounds within the first week in order to quickly cover exposed bone, tendons and neurovascular structures, which is crucial if the risk of infection, osteomyelitis, nonunion and further tissue loss is to be decreased [1]. This, however, is often impracticable because of a complex fracture, wound contamination or pre-existing infection. Furthermore, associated injuries accompanied by hemodynamic instability and microcirculatory dysfunction based on systemic inflammation or edema, as often seen in polytraumatized patients, prevent early, long-lasting reconstructive surgical intervention. Although skin grafts are readily obtainable, they depend on the vascularity of the recipient site and may be contraindicated by exposed bone, cartilage, tendons or surgical implants. Therefore, multiple ''second-look'' operations are necessary prior to definitive wound closure. The essential tasks of an appropriate dressing for temporary wound coverage are to prevent the exposed vital structures from desiccation and bacterial contamination as well as to induce local proliferation of granulation tissue. Hence, VT, by sterilizing the wound and stimulating the formation of granulation tissue, not only provides adequate temporary wound coverage before definitive closure but also allows for a much more flexible time schedule [41].

Fleischmann et al. [6] were the first to report on 15 patients with open fractures treated by vacuum sealing. It was stated that VT resulted in efficient cleaning and conditioning of the wound with marked proliferation of granulation tissue, and that bone infection did not occur. In 2003, Huang et al. [7] prospectively compared 18 patients with open fractures and soft-tissue defects treated by primary osteosynthesis, debridement and VT before definitive wound closure and 14 patients presenting with similar injuries treated traditionally by external fixation and open wound management followed by secondary osteosynthesis and soft tissue closure. None of the patients treated by VT showed complications with the healing of fractures as well as soft tissue, and there were statistically significant advantages with regards to time of treatment, total cost and complication rate in this group. Parrett et al. retrospectively analyzed 290 open tibia–fibula fractures over a 12-year (1992–2003) period and found a marked decrease in the need for free flaps for definitive wound closure in parallel with increased use of VT in the last four-year period [1]. However, despite this trend, they found no change in infection, amputation or malunion/nonunion rates. In contrast, our own group compared VT to alternative dressing as a temporary coverage for soft tissue injuries in Gustilo type IIIA and type IIIB open fractures. VT was used in 14 patients and Epigard™ in 12 patients. Besides one amputation observed in each group, a substantially (although not statistically significant) smaller infection rate in patients treated with VT was noted, in spite of higher morbidity (more type IIIB open fractures and more polytraumatized patients) [2]. Thus, in this study, VT seemed to reduce the infection rate in severe open fractures as compared to alternative temporary wound dressings.

In general, all of the publications attribute their successful treatments to the abovedescribed characteristics of VT, such as optimization of blood flow, decrease of local tissue edema, removal of contami-

nated wound fluid, as well as stimulation of granulation tissue formation. However, most of the results must be interpreted carefully, as these studies lack larger patient numbers, randomization or even control groups, and there are considerable differences in the treatment goals and interpretation of results [11]. Hence, although VT is now regarded as a reasonable and versatile tool for temporary wound coverage in severe open fractures of the lower extremity, there is still a considerable deficit of well-designed studies that document its efficiency [4]. It cannot be emphasized enough that thorough and repetitive surgical wound debridement and microvascular flaps remain cornerstones in the treatment of severe open fractures of the lower leg. In addition to these, VT should be included in the management of these injuries for temporary wound coverage and conditioning of soft tissues. This has been shown in more recent and methodically improved studies which also demonstrate that although VT cannot replace free flap transfer, it does allow a more flexible timeline and it improves safety until definitive soft tissue closure [2, 5, 7].

Conclusion

Vacuum therapy can be regarded as a reasonable and versatile tool for temporary wound coverage in severe open fractures of the lower leg, as it is technically simple to apply, it is generally well tolerated by patients, and it has low complication rates. The treatment success of VT is mainly attributed to optimization of blood flow, decrease of local tissue edema, reduction of bacterial count, as well as stimulation of granulation tissue formation. VT should be included in the management concept for severe open fractures of the lower leg since it provides not only safe temporary wound coverage but also soft-tissue conditioning, allowing for a more flexible schedule until definitive soft-tissue coverage. However, despite the obvious clinical significance of VT, further studies investigating the superiority of VT compared to alternative wound dressings and the exact underlying mechanisms that lead to the apparent improved wound healing are needed.

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