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Negative Pressure Wound Therapy: A Mini-Review on 'mechanism, applications, and clinical insights'

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Abstract
Background: Wounds that are chronic and complex at the same time continue to be a main clinical problem globally, frequently resulting in the patient's wellness being compromised for a long time, huge medical expenses, and low quality of life for the patient. Negative pressure wound therapy NPWT or vacuum-assisted closure VAC has been considered the most superior wound management method and has gained broad clinical acceptance in the last twenty years.
Objective: This paper serves as a survey aiming to dissect the biological mechanisms, clinical indications, contraindications, procedural considerations, and current evidence supporting NPWT in detail. Furthermore, it addresses future directions and innovations in NPWT.
Methods: For the period of 1997-2025 literature covering the topic was systematically reviewed from the databases PubMed, Scopus, and Web of Science using the terms negative pressure wound therapy, vacuum-assisted closure, chronic wound management, and wound healing technology. Randomized controlled trials RCTs, meta-analyses, and evidence-based clinical guidelines were given priority.
Results: Evidence shows that NPWT leads to quicker closure of the wound, lower infection risk, and better granulation tissue formation. It has been proven to be useful for diabetic ulcers, pressure injuries, surgical wounds, burns, traumatic injuries, and defects in the skin. Not treating osteomyelitis, necrotic tissue with eschar, malignancy in the wound, and exposing vital structures are counted as contraindications by the authors.
Conclusion: NPWT is still a very powerful method when used in the correct clinical situations. Combining it with instillation systems, wearable technology, and smart sensors will likely pave the way for more effective therapeutics. Device design and manufacturing of NPWT should comply with relevant international safety and quality standards such as ISO 13485 (Medical devices—Quality management system).

Keywords: Negative pressure wound therapy, vacuum-assisted closure, chronic wounds, surgical site management, burn wounds, granulation tissue formation

Introduction

The field of wound management has made remarkable progress, but still, chronic and complicated wounds are the ones that the healthcare system has to struggle with the most. Among chronic wounds, diabetic foot ulcers, pressure ulcers, and venous leg ulcers are the most common, affecting millions of people and contributing to healthcare costs of billions of dollars every year all over the world [1]. The healing process of these wounds is frequently kept in the inflammatory phase because of either poor blood supply, ongoing infection, or the metabolic disorders [2]. Negative pressure wound therapy NPWT was developed in the late 1990s, with the initial work of Morykwas and Argenta who showed that the application of subatmospheric pressure on wounds facilitated the production of granulation tissue, decreased bacterial counts, and improved blood vessel formation [3, 4]. Even though it was first limited to special surgical units, NPWT is now part of the wound management protocols and has been adopted in various fields of medicine like plastic surgery, orthopedics, vascular surgery, and burn care [5].

Mechanism of Action

NPWT promotes healing through four interrelated mechanisms:

1. Macro deformation

The negative pressure draws wound edges together, reducing the size of the defect and facilitating epithelial migration [6].

2. Micro deformation and Cellular Mechano transdion

On a microscopic scale, the foam dressing transmits micro-strains to cells in the wound bed. These mechanical forces stimulate fibroblast proliferation, collagen deposition, and angiogenesis through mechanotransduction pathways [7, 8].

3. Fluid and Exudate Removal

NPWT continuously removes wound exudate, decreasing interstitial edema, which improves local perfusion and oxygen delivery. Reduced exudate also decreases protease activity, which can otherwise degrade extracellular matrix components [9].

4. Bacterial Load Reduction

By maintaining a closed, moist environment and removing contaminated fluid, NPWT reduces bacterial colonization, lowering the risk of wound infection [10].

Clinical Indications

NPWT has broad applications across wound types [11–14]:

- **Chronic wounds:** Diabetic ulcers, venous ulcers, and pressure ulcers.
- **Acute traumatic wounds:** Crush injuries, degloving injuries, and open fractures.
- **Surgical wounds:** Prophylactic use over high-risk incisions reduces surgical site infections.
- **Burns:** Prepares partial-thickness burns for grafting.
- **Skin defects:** Prepares wound bed for grafts or flaps.

Contraindications

According to the Wound, Ostomy and Continence Nurses Society (WOCN) guidelines [15], NPWT should not be applied to:

- Necrotic tissue with eschar.
- Untreated osteomyelitis.
- Malignancy in the wound bed.
- Exposed organs, vessels, or nerves.
- Non-enteric, unexplored fistulas.

Procedural Considerations

1. Preparation

- Debride necrotic tissue.
- Irrigate the wound thoroughly.
- Achieve hemostasis before sealing

2. Application

- Place foam or gauze dressing into wound cavity.
- Seal with adhesive drape to create airtight closure.
- Connect drainage tubing to vacuum pump.
- Apply continuous or intermittent suction, generally −125 mmHg (adjusted based on wound type and patient tolerance).

3. Dressing Change Frequency

Every 48–72 hours, or more frequently for infected wounds.

Evidence from Clinical Studies

1. Chronic Wounds

A meta-analysis of 11 RCTs found NPWT reduced healing time in diabetic foot ulcers by 25–35% compared to standard moist dressings [12].

2. Surgical Wounds

Prophylactic NPWT reduced surgical site infection rates in orthopedic trauma by up to 50% in high-risk patients [13].

3. Burns

NPWT improved graft take rates and reduced time to definitive closure [14].

Advantages of NPWT

- Accelerated healing.
- Reduced infection risk.
- Decreased frequency of dressing changes.
- Enhanced patient mobility (with portable devices).
- Lower long-term treatment costs [16].

Limitations and Complications

While Negative Pressure Wound Therapy NPWT has demonstrated significant clinical benefits in promoting wound healing, it is not without limitations and potential adverse effects. Awareness of these factors is critical for appropriate patient selection, therapy optimization, and risk mitigation.

- **Pain During Dressing Changes**

NPWT is frequently associated with pain, which is one of its commonest drawbacks, especially dressing removal and change. The sticking of foam or gauze to the wound can result in the tearing of granulation tissue and thus, the patient may feel discomfort or even acute pain. This is especially the case for wounds with nerve endings, burns, or very delicate tissues. To lessen pain, different approaches can be used: for example, giving analgesics before the procedure, using instillation therapy to wet dressings before removing them, and applying non-adherent interface layers.

- **Risk of Bleeding in Highly Vascular Wound Beds**

In the case of profusely vascularized wounds or those with fragile tissues, the application of NPWT may lead to bleeding, particularly if accidental tearing of granulation tissue occurs during dressing changes. Patients taking blood-thinning drugs or having bleeding disorders are the most vulnerable ones. It is advisable for health professionals to be careful, keep a lookout for signs of bleeding, and think about lowering the suction pressure in such instances.

- **Difficulty in Sealing Irregular or Moist Periwound Skin**

It can be difficult to obtain an airtight seal on wounds that have irregular shapes, deep undermining, or in places that move a lot, like joints. If the skin around the wound is moist because of sweating or leakage of exudate, that would be a reason for the drapes' adhesion to become weak and thus therapy to bounce back. The use of skin preparation agents, hydrocolloid strips, and customized drape cutting techniques may help in keeping the seal intact during such situations.

- **Potential Maceration if Seal Integrity is Compromised**

Loss of vacuum due to an imperfect seal or leakage can cause pooling of wound exudate, leading to maceration of surrounding skin. Maceration weakens skin structure, increasing the risk of secondary breakdown and infection. Preventive strategies include frequent monitoring of the dressing seal, timely replacement of drapes, and the application of protective skin barriers around the wound margin.

Future Directions

The realm of Negative Pressure Wound Therapy (NPWT) is still developing with research and technological innovations going on to improve patient outcomes, make it more convenient for users, and cut down on treatment costs. A number of promising directions are opening up:

- **NPWT with Instillation Therapy (NPWTi)**

NPWTi is the combination of negative pressure and the periodic automated instillation of fluids like sterile saline, antiseptic, or antimicrobial agents. The treatment helps by getting rid of biofilms, lowering the number of bacteria, and aiding the process of detaching and removing dead tissue. It has been particularly effective in treating infected, contaminated, or hard-to-heal wounds, where breaking down the biofilm is the key to faster healing. NPWTi also allows for the simultaneous mechanical and chemical cleansing of the wound through the integration of programmed dwell times and controlled fluid delivery without therapy being interrupted.

- **Portable, Wearable NPWT Devices**

The advent of miniaturized, battery-powered NPWT devices has unlocked the door for patients with greater freedom of movement and, therefore, earlier discharge from the hospital and wound care at home. These units are very light, unobtrusive and meant for one patient only, which lowers the chance of cross infection. The use of NPWT in a wearable format not only brings about the comfort of the

patient but also contributes to the outpatient treatment of chronic wounds and so, health care resources are not as heavily relied upon. Moreover, new developments in the areas of rechargeable battery life, silent pump operation, and disposable canister technology are all helping make these devices more suitable for use in the patients' own homes.

- **Sensor-Integrated NPWT Systems**

The integration of biosensors into NPWT devices represents a significant leap toward precision wound care. These sensors can monitor critical parameters such as negative pressure stability, exudate volume, pH, temperature, and even bacterial load in real time. Data can be transmitted wirelessly to clinicians, enabling remote monitoring and timely interventions. In the future, such "smart" NPWT systems could incorporate predictive analytics and artificial intelligence algorithms to tailor suction parameters dynamically, based on individual wound healing progress.

- **Combination Therapies and Regenerative Medicine Integration**

Outside the current situation, there is an increasing curiosity about combining NPWT with regenerative approaches, like delivering growth factors, applying stem cells, and using bioengineered tissue scaffolds. All this together could greatly speed up the process of closing wounds, particularly in patients with poor healing capacity, e.g., those who suffer from diabetes or have poor blood circulation.

Conclusion

NPWT is a versatile treatment supported by evidence that has greatly changed wound care for the better. When provided to proper patients and wound types, it can quicken healing, decrease infection risk, and enhance life quality. Constant innovation guarantees to boost its features, thus making NPWT a vital component of advanced wound management in the next few decades.

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