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Negative Pressure Wound Therapy in Surgical Wound Management: Mechanisms, Clinical Outcomes, and Comparative Analysis of Modern NPWT Systems

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ABSTRACT

Introduction: Surgical wounds that fail to heal or that develop complications such as infection or dehiscence are challenging problem that health care has to deal with everyday. Negative Pressure Wound Therapy (NPWT) has emerged as an important tool for managing complex wounds. This review aims to summarize the mechanisms by which NPWT supports wound healing, estimate the clinical efficacy of NPWT in surgical wounds and compare available NPWT systems.

Materials and methods: A literature review was conducted using the databases such as Pubmed and Google Scholar.

State of Knowledge: NPWT involves a sealed dressing attached to a suction pump that applies subatmospheric pressure to the wound. There are four major mechanisms that lead straight to the effect: microdeformation [14]; macrodeformation [13], fluid removal [15]; stabilization of wound environment [11]. Clinically, NPWT has demonstrated improved healing rates in chronic wounds (e.g., diabetic foot ulcers) [5, 6] and decreased surgical site infection and seroma in high-risk surgical incisions [7, 8].

Conclusions: NPWT upgrades healing by stabilizing environment of wound, enhancing granulation and closing wound faster. Evidence confirms its efficacy in reducing wound complications in both open and closed surgical wounds. NPWT has become an invaluable tool in surgical wound management, however it is still important to use it in selected group of patients.

Keywords: Negative Pressure Wound Therapy (NPWT), Vacuum-assisted closure (VAC), wounds healing; surgical wounds

Introduction

Surgical wound healing is a main aspect of postoperative recovery, yet a substantial proportion of surgical wounds encounter complications such as infection, dehiscence (reopening of the incision), or chronic non-healing. These complications may result in longer hospitalization, reoperations or increased morbidity. Negative Pressure Wound Therapy (NPWT) has improved the management of complex wounds over the past two decades. NPWT involves the application of controlled suction to a wound through a sealed dressing attached to a vacuum pump.

The main problem which NPWT solves is how to increase healing and minimize complications in wounds that might not heal well in circumstances of traditional dressings. Former studies and clinical reports have shown promising results with NPWT in various wound types, such as chronic ulcers, traumatic wounds, and surgical incisions at risk of infection [3]. However, the mechanisms of work, the strength of evidence for its clinical efficacy and differences between a variety of systems of NPWT are still raise doubts.

The purpose of this review is to provide a comprehensive overview of NPWT in the context of surgical wound healing. Firstly we discuss the current understanding of how NPWT works at the tissue level to accelerate healing (Mechanisms of Action). Secondly we review the clinical evidence for NPWT's effectiveness, both in open surgical wounds and chronic wounds (such as those resulting from infection or delayed healing) and in primarily closed incisions (prophylactic use to prevent complications). Finally, we compare the features and performance of available NPWT systems, including traditional VAC devices and newer ones, and consider practical aspects such as safety and future directions. By consolidating findings from over three decades of research, this review aims to clarify the role of NPWT in surgical wound care and provide guidance for its optimal use.

Current State of Knowledge

1. Mechanisms of Action of NPWT

NPWT promotes wound healing through these four basic mechanisms:

1. Macrodeformation (wound contraction):
   The suction force causes the foam dressing to contract by up to ~80% of its volume [14]. Due to the foam's adherence to the wound edges, the edges draw inward, effectively decreasing the wound size. This macroscopic wound contraction under NPWT reduces the amount of tissue that must regenerate to achieve closure. The level of macrodeformation depends on tissue elasticity; for example, wounds in more flexible areas will contract more than those in rigid or high-tension areas [14]. By narrowing wound gaps, NPWT makes faster closure through secondary intention (granulation and epithelialization) or by enabling delayed primary closure or grafting with a smaller defect.
2. Microdeformation (cellular stimulation):
   At the microscopic level, NPWT promotes deformation of cells and the extracellular matrix, which in turn stimulates biological responses. The negative pressure initiates micro-strain in the wound tissue (on the order of 5–20% deformation) [14]. This mechanical stress is transduced by cells (mechanotransduction), starting a cascade of cellular proliferation and angiogenesis (new blood vessel formation) [14]. Saxena et al. demonstrated that NPWT foam causes an undulating microstrain pattern in the wound bed that leads to robust granulation tissue formation [13, 21]. Importantly, Morykwas et al. showed in a pig model that NPWT increased granulation tissue formation by ~60% in comparison to the standard gauze dressings [3]. Healthy tissue matrix made from the rapid granulation tissue accelerate wound closure. At the cellular level, studies have indicated increased fibroblast proliferation and division under NPWT, as well as upregulation of growth factors in the wound environment [21, 3]. There, boosted angiogenesis has been observed, under NPWT which improve

perfusion within the wound bed. To sum up, these microdeformation-induced effects jump-start the normal healing phases (proliferation and remodeling).

3. Removal of fluids and edema:

   NPWT continuously evacuates wound fluid (exudate) and edematous fluid from the tissue. Draining this excess fluid causes reduction of swelling and tissue pressure which is beneficial because of main two reasons: firstly by improving microcirculatory blood flow to the wound (since edema can compress capillaries and impede perfusion); secondly by removing soluble factors in the wound fluid that can inhibit healing [15]. Chronic wound fluid is known to contain high levels of inflammatory cytokines and proteases (such as TNF-α and matrix metalloproteinases) that break down extracellular matrix and growth factors [15]. Through removal of these substances NPWT makes on environment which is more favorable toward healing process. [15]. Stechmiller et al. found that NPWT significantly decreased levels of TNF-α and MMPs in wound fluid, correlating with improved healing outcomes [15]. The fluid flow created by the vacuum may also generate shear stress and microcurrents in the wound, which have been hypothesized to stimulate cell migration and granulation. By preventing fluid accumulation, NPWT also decreases the risk of seroma or hematoma formation in surgical wounds, which are common precursors to infection.

4. Stabilization of the wound environment:

   NPWT dressings serve as a semi-permeable barrier over the wound. On the contrary to traditional gauze dressings that need to be changed daily, NPWT dressings can be changed after 2-3 days during which they maintain pro-healing environment.[15]. There are several advantages from sealed wound, such as protection from external contamination - the occlusive drape is impermeable to bacteria and debris [15]; moist, warm environment is maintained by preventing desiccation and heat loss [15]. Wounds heal more efficiently at normal body temperature and moisture levels, as evidenced by studies like Kloth et al. on normothermic wound therapy [15]. NPWT ensures the wound is not subject to the cooling and drying that occur with frequent dressing exposure. Moreover, the physical stabilization (immobilization) of the wound by the foam and drape can reduce mechanical stress and shearing at the wound site, further promoting tissue regeneration. To sum up, NPWT creates an optimal milieu for the healing process by serving as a temporary synthetic "skin" that works as a shield for the wound and modulates its microenvironment.

There is a connection between these four mechanisms and the total effect is way more significant than the result of each of them working separately. As an example, NPWT removes fluid and reduces edema, local blood flow and oxygen delivery improve, which in response supports the formation of granulation tissue under the microdeformational stimuli. The process result is mostly a faster and more robust healing response than would occur with passive wound dressings. In general NPWT is safe and well-tolerated, but despite of all positive aspects some certain risks can be observed. The intense suction and occlusion can, in rare cases, lead to complications if not monitored: e.g., tissue ischemia from excessive suction, bleeding from capillary or vessel erosion, or infection if the system is left in place too long without change [19, 20]. Fortunately, such unfavorable events are infrequent, and careful adherence to protocols (appropriate pressure settings, regular dressing changes, and debridement of necrotic tissue before NPWT) mitigates these risks [19, 20]. Overall, the mechanism of NPWT represents a prime example of harnessing biomechanical forces to therapeutically modulate wound healing – a synergy of engineering and biology that has been validated in both laboratory and clinical studies.

2. Clinical Efficacy of NPWT in Surgical Wounds

2.1 NPWT in Chronic and Open Wounds

NPWT was originally intended for open traumatic and chronic wounds, and many clinical studies have proved the beneficial outcome of using this device in these type of wounds. One of the landmark randomized controlled trials was conducted by Armstrong and Lavery on diabetic foot wounds [5]. In that multicenter trial, 162 patients with partial foot amputations (transmetatarsal-level diabetic foot wounds) were treated with either NPWT or standard moist dressings for up to 16 weeks [5]. The NPWT group had a significantly higher healing rate: 56% of NPWT-treated wounds achieved complete closure, compared to 39% in the control group ($p = 0.04$) [5]. Furthermore, wounds treated with NPWT healed faster – the median time to full closure was shorter in the NPWT group (by roughly 4 weeks) [5]. NPWT-treated patients also showed more rapid granulation tissue formation, indicating early progression of healing [5]. Notably, wound infections in NPWT-treated and controls were on similar level, indicating that despite of closed environment, NPWT did not increase risk of the infection [5]. In fact, by accelerating closure, NPWT potentially reduces long-term infection risk. Armstrong et al. concluded that NPWT is a safe and effective treatment for complex diabetic foot wounds, leading to a higher proportion of healed wounds and potentially fewer repeat amputations [5].

Another important trial in diabetic foot ulcers was conducted by Blume et al. [6]. This study enrolled 342 patients with chronic diabetic foot ulcers and compared NPWT (VAC therapy) to advanced moist wound therapy (AMWT, using modern dressings like hydrogels) over a 112-day period [6]. The results showed NPWT superiority: 43.2% of patients in the NPWT group achieved complete wound closure, versus 28.9% in the AMWT group ($p = 0.007$) [6]. Moreover, NPWT decreased the median time to ulcer closure and led to fewer secondary amputations [6]. By 9 months of follow-up, the durability of closure was similar between groups, but the initial healing advantage of NPWT was clear [6]. These results indicated that NPWT, in comparison with advanced conventional dressings, makes chronic wounds healing more efficient. Smaller randomized studies have similarly shown improved healing of deep or postoperative diabetic foot wounds with NPWT versus saline gauze (e.g. McCallon et al. reported quicker healing in NPWT-treated post-operative foot ulcers, 22.8 days vs 42.8 days) [22]. Taken together, there is a high level of evidence that NPWT facilitates closure of diabetic foot wounds, which are a common and costly surgical problem.

Beyond diabetic ulcers, NPWT has been applied to pressure ulcers (bedsores) and other chronic wounds (venous ulcers, etc.). The clinical evidence here is ambiguous. Some case series and interim analyses suggested NPWT can help clean and shrink pressure ulcers, possibly making them more amenable to closure with flaps or grafts [23]. For instance, an early trial by Ford et al. compared NPWT to a hydrocolloid-based wound system in pressure ulcers and observed trends favoring NPWT in wound size reduction, although the study was underpowered [23]. However, larger systematic reviews have pointed out the lack of conclusive RCT data in pressure ulcers. A 2015 Cochrane Review (updated 2023) of NPWT for treating pressure ulcers found no clear evidence of benefit, largely due to too few high-quality trials [9]. Only four small RCTs (149 total patients) were included, with very low-quality evidence and inconsistent results; the authors concluded that there is “no rigorous RCT evidence” and high uncertainty regarding NPWT in pressure ulcers [9]. This does not mean that NPWT is not effective and should be excluded from the treating of pressure ulcers but indicates that there should be more researches done on this subject. It also underlines an important principle: NPWT should be used in conjunction with standard ulcer care (e.g. offloading, adequate debridement, nutrition optimization), and not as a standalone miracle cure. Generally, for open surgical wounds (such as dehisced incisions or trauma wounds left open), NPWT is widely regarded as beneficial. It helps control wound bed moisture and infection while accelerating granulation, often allowing earlier closure or grafting [4]. Randomized trials in orthopedic trauma have shown NPWT can reduce the time to readiness for closure in open fracture wounds [24], though a 2018 Cochrane Review on NPWT in open fractures indicated that definitive evidence of long-term benefit (e.g.

reduced chronic osteomyelitis or improved limb salvage) is still limited [33]. Nonetheless, NPWT has become standard of care for many complex open wounds due to the substantial clinical improvements observed in practice.

2.2 NPWT in Closed Incisions (Incisional NPWT)

Using NPWT as an preventive method on closed surgical incisions to minimize complications, made a great interest, especially in patients at high risk for wound infection or breakdown (for example, obese patients, orthopedic trauma incisions, sternotomy in cardiac surgery, etc.). This application, often called closed-incision NPWT (ciNPWT), includes placing an NPWT dressing over a primarily closed wound immediately after surgery, usually for a few days postoperatively. The hypothesized positive effects include improved perfusion at the incision, reduced edema, and continuous drainage of any wound fluid that might accumulate, thereby reducing stress on the incision and risk of dehiscence or infection.

Multiple studies have evaluated incisional NPWT, and evidence is steadily accumulating. A 2016 meta-analysis by Hyldig et al. pooled 10 randomized trials (1,089 patients) testing NPWT on closed incisions in various surgeries [7]. The meta-analysis found that incisional NPWT was associated with a significantly lower incidence of surgical site infection (SSI) compared to standard dressings – the relative risk of infection was ~0.54 (95% CI 0.33–0.89) in favor of NPWT [7]. NPWT also halved the risk of seroma formation (RR ~0.48) [7], presumably by the aforementioned fluid removal mechanism. However, the reduction in wound dehiscence with NPWT was not statistically significant in that analysis [7]. The authors calculated a number-needed-to-treat (NNT) of ~25 to prevent one infection, and as low as 3 to prevent one seroma [7]. Due to heterogeneity among the included studies (different surgical disciplines, varying patient risk profiles), the overall quality of evidence was rated moderate, and the authors urged caution in making blanket recommendations [7]. At that time, they concluded that while results were promising, more uniform data were needed before incisional NPWT could be universally recommended.

Since 2016, several large trials and additional meta-analyses have been completed, further clarifying the role of incisional NPWT. Notably, an up-to-date meta-analysis in 2023 by Groenen et al. incorporated dozens of RCTs and even employed trial sequential analysis to gauge if enough evidence has been accumulated [8]. This comprehensive analysis found high-certainty evidence (by GRADE criteria) that incisional NPWT significantly reduces the risk of SSI in surgical wounds across various specialties [8]. The authors reported that the confidence interval for the risk reduction has narrowed with recent trials, and the pooled data crossed the futility boundary, suggesting that further RCTs are unlikely to change the conclusion [8]. To sum up, these most up-to-date results confirmed that prophylactic NPWT is effective in preventing infections in closed surgical incisions, especially in high-risk cases. This represents a maturation of evidence compared to earlier conflicting results.

It is important to identify which patients benefit most from incisional NPWT. Many studies focus on high-risk patients: for example, obese patients undergoing colorectal or obstetric surgery, or patients with contaminated wounds, long surgical duration, or significant comorbidities. Guidelines have started to reflect the positive evidence. The World Health Organization (WHO) in 2018 issued a guideline suggesting the use of NPWT on closed incisions in high-risk surgical patients to prevent SSI, albeit noting the evidence then was of low quality and based on a limited number of studies [8]. Around the same time, the U.K. National Institute for Health and Care Excellence (NICE) in 2019 recommended a specific single-use NPWT device (PICO system) for closed-incision management in high-risk patients, citing potential cost savings from avoided infections [8]. By contrast, some health agencies (like the U.S. CDC in 2017) did not include incisional NPWT in their guidelines, reflecting earlier uncertainty [8]. However, with the new high-certainty data, we can expect broader consensus emerging. For example, in orthopedic trauma, incisional NPWT is increasingly standard for high-risk fractures or large implants; in cardiac surgery, NPWT dressings over sternotomies in obese or diabetic patients have been shown to sharply reduce deep sternal wound infections [29]; and in colorectal surgery, where SSI rates can be high, trials have shown NPWT can cut SSI incidence significantly (one trial in obese colorectal surgery patients showed a drop from 30% to ~18% SSI with NPWT) [25].

It should be noted that incisional NPWT is not necessary for every surgical patient. For low-risk, clean cases, the cost and complexity may not be justified if baseline infection risk is already very low. But for selected patients – e.g. those with obesity, diabetes, immunosuppression, or surgeries with long incisions or high bacterial load – NPWT can be a valuable preventive measure. The goal is to mitigate postoperative wound complications, which in turn improves patient recovery and reduces healthcare costs. A recent Cochrane review (2020 update) on NPWT for closed surgical wounds concluded that NPWT "probably results in fewer SSIs" than standard dressings in high-risk wounds, but called for more data on other outcomes and cost-effectiveness [26]. Now that efficacy in preventing infection is well-supported, current research is also examining effects on other outcomes like wound dehiscence, scar quality, and patient comfort. Some studies have noted NPWT might reduce hematoma formation and even improve the quality of the surgical scar by minimizing tension and inflammation at the incision. These ancillary benefits remain an area of active investigation.

In summary, NPWT has demonstrated significant clinical efficacy in two broad arenas of surgical wound care: (1) as a treatment for open wounds (acute or chronic) to accelerate healing, and (2) as a prophylactic dressing for closed incisions to prevent complications.

In complex open wounds (such as infected laparotomy wounds, dehisced sternal wounds, traumatic extremity wounds, diabetic foot amputations), NPWT has repeatedly shown the ability to achieve faster wound closure and enable earlier definitive surgical closure (via secondary suture or graft) than conventional methods [5, 6]. In primarily closed wounds at risk of infection, NPWT significantly lowers the incidence of postoperative infections and seromas [7, 8]. However, NPWT is not a panacea; its success depends on proper usage (adequate debridement, appropriate pressure settings, timely dressing changes) and it may not markedly benefit wounds that are already low-risk or that have unresolved underlying issues (e.g. untreated ischemia or osteomyelitis). The overall clinical message is that NPWT is a powerful adjunct that, when applied to the right patient at the right time, can greatly improve surgical wound outcomes.

2.3 Comparison of Available NPWT Systems

Since the introduction of the original VAC device by KCI (Kinetic Concepts Inc., now 3M) in the 1990s, numerous NPWT systems have been developed by different manufacturers. While the core principle remains the same (a sealed wound dressing attached to a vacuum source), systems can differ in their dressing materials, pump technology, and usability features. This section compares the major categories of NPWT systems, highlighting their differences, and reviews any evidence comparing their performance.

- Traditional Foam-Based NPWT vs. Gauze-Based NPWT:

The classic NPWT setup uses a foam dressing (often polyurethane foam with open pores, e.g. GranuFoam™) under an occlusive drape [13]. The foam is popular because its porous structure distributes suction evenly and it actively contracts under negative pressure, aiding macrodeformation. An alternative filler for NPWT dressings is gauze (cotton gauze moistened with saline). Gauze-based NPWT was anecdotally used in the early VAC prototypes and remains in some commercial systems (e.g. Smith & Nephew’s Renasys system allows gauze). Gauze does not shrink as much as foam; experiments have shown that under -125 mmHg, a foam dressing contracted to ~40% of its original area while gauze reduced only to ~88% [13]. Thus, foam achieves substantially greater wound contraction, which likely translates to more mechanical stimulation of the wound. Foam is also non-absorbent, allowing fluid to be wicked through to the tubing and collection canister, whereas gauze will absorb some exudate and can become soggy [13]. Retained fluid in gauze might lead to prolonged contact of the wound with proteases or bacteria, potentially lessening the fluid-removal benefit of NPWT. Because of these factors, most clinicians favor foam dressings for NPWT, especially in deep or irregular wounds where foam can fill the cavity and maintain space under the drape. Indeed, virtually all RCTs in the literature (including those cited above) utilized foam-based NPWT [13]. It should be noted that there have been no large RCTs directly comparing gauze vs. foam NPWT in equivalent conditions [13]. The choice often comes down to provider preference or specific wound scenarios (for instance, some might use gauze NPWT in superficial wounds to avoid ingrowth of tissue into foam). Gauze NPWT may also be more cost-effective in some settings and can result in fewer dressing adherence issues (foam can sometimes adhere strongly to the wound bed). A clinical perspective by Miller et al. argues that gauze NPWT has fewer foam-related complications (like foam fragment retention) and lower material cost, making it a reasonable option in appropriate cases [13]. Overall, both foam and gauze can achieve the desired wound healing outcomes, but foam tends to yield faster granulation and wound contraction [13]. Modern NPWT kits often include specialized foam types (black polyurethane foam for general use, white polyvinyl alcohol foam for tunnels or delicate structures) to tailor the therapy to the wound type.

- Reusable NPWT Devices vs. Single-Use Portable Devices:

Traditional NPWT systems (e.g. 3M/V.A.C. Ulta™, Smith & Nephew Renasys™) consist of an electric pump unit, canister to collect fluid, and the dressing assembly. These pumps are usually AC-powered (with battery backup), capable of delivering continuous or intermittent suction at various set pressures (commonly -125 mmHg, range -50 to -200 mmHg) [18]. They often have alarms for leaks, canister full, etc., and are designed for use in hospital settings (though portable versions exist). In the past decade, disposable single-use NPWT devices have been introduced, primarily for closed incisions or small wounds. One example is the PICO™ system (Smith & Nephew), which is a palm-sized battery-powered unit attached directly to a small dressing with an integrated absorbent layer (no separate canister). PICO provides a constant -80 mmHg and is designed for short-term use (up to ~7 days) on closed incisions or low-exudate wounds. The benefits of such devices are their simplicity (one piece, no tubing to manage exudate externally) and patient mobility – they are lightweight and can easily be used in outpatient settings [18]. Clinical studies have shown PICO is effective in reducing SSI in high-risk surgical patients, which led NICE to specifically recommend it for prevention of wound complications [27]. Another development is mechanically-powered NPWT devices, such as the SNaP® system (Spiracur/3M). These omit any electronic pump; instead, they use an internal spring mechanism to generate a constant suction (e.g. -125 mmHg) [18]. The SNaP device is very lightweight (<< 100 grams) and disposable. It attaches to a small canister on the wound dressing, and negative pressure is generated by recoil of springs – essentially a mechanical vacuum. Studies comparing SNaP to traditional electric VAC in chronic wounds found no difference in healing outcomes but noted that patients had greater mobility and satisfaction with the small device [18]. Fong and Marston reported that the mechanically powered NPWT had similar efficacy in wound size reduction and granulation as standard NPWT, while improving portability for ambulatory patients [18]. These portable systems extend the reach of NPWT beyond the hospital, allowing therapy to continue at home conveniently.

Comparative Performance: With multiple NPWT systems on the market (3M/KCI VAC, Smith & Nephew Renasys and PICO, Cardinal Health™ NPWT, Medela Invia®, Mölnlycke Avance®, etc.), an important question is whether any particular device is superior in clinical outcomes. There have been relatively few head-to-head trials, but the data available suggest that all properly functioning NPWT systems achieve comparable results in wound healing. For example, a large retrospective study by Hurd et al. reviewed over 1,000 patients treated with either the VAC (foam-based) or the Renasys system (gauze-based) [10]. The healing outcomes were essentially equivalent: ~90–94% of patients in both groups reached their treatment goal (wound closure or adequate granulation for surgery), with no significant differences in time to healing, wound area reduction, or complication rates [10]. No clinically meaningful advantage of one system over the other was found [10]. This suggests that as long as the NPWT principles are applied (appropriate pressure, adequate seal, etc.), the brand or filler type is not critical to success in most cases. Another study (a preclinical pig model) compared three NPWT systems – a traditional foam VAC, a Prevena™ incision NPWT (foam dressing for closed incisions by KCI), and PICO – and found all produced similar biological effects, with only minor differences in wound contraction or histology [25].

Thus, clinicians can base their choice of NPWT device on practical considerations: availability, cost, user-friendliness, and the specific wound scenario. For example, for a large exudative abdominal wound, a device with a high capacity canister and strong suction may be preferred (traditional NPWT). For a small orthopedic incision in an outpatient, a PICO or similar disposable device may suffice and improve comfort. It is worth mentioning that some newer NPWT systems have specialized features – NPWT with instillation (NPWTi) is a notable innovation. These systems (like 3M V.A.C. VeraFlo™) periodically instill a sterile solution (such as normal saline or antimicrobial fluid) into the wound, soak for a set time, and then suction it out. NPWTi aims to combine the benefits of NPWT with automated wound irrigation to help manage bioburden. Early studies suggest NPWTi can expedite clearance of infection in wounds that failed standard NPWT [17]. Kim et al. reported that in a retrospective comparison, NPWTi improved outcomes in infected wounds compared to standard NPWT alone [17]. While NPWTi is a promising advance, it requires more complex equipment and solution handling, and thus is typically reserved for severe or recalcitrant wound infections at present.

2.4 Cost and Logistics

NPWT therapy, particularly with proprietary devices, can be expensive. Cost considerations include the price of the disposable dressings and canisters, rental or purchase of pump units, and the manpower for dressing changes. Several analyses have found that if NPWT prevents even a single major complication (like deep infection or re-operation), it becomes cost-effective due to the high cost of those complications [27]. For prophylactic use, health economic models (such as those considered by NICE) determined that in high-risk surgical patients, the upfront cost of an incisional NPWT dressing can be offset by the reduction in SSI treatment costs [27]. On the other hand, indiscriminate use in low-risk cases would not be cost-effective. From a health systems perspective, NPWT has spurred the development of wound care teams and home care programs, since managing NPWT dressings requires some expertise. Many hospitals have NPWT protocols to ensure appropriate use and to train staff in handling the devices. Portable and disposable systems ease the burden by simplifying the device operation for patients at home, potentially reducing nursing visits. In comparing systems, cost may also vary: foam dressings and canisters for the VAC might be costlier than simpler gauze systems or single-use devices, but the difference is often marginal relative to the overall treatment course.

In terms of safety, all NPWT systems share similar profiles. Common minor issues include skin irritation from the adhesive drape and discomfort during dressing changes. Serious complications are uncommon but have been reported: e.g., cases of bleeding due to inadvertent erosion of a vessel, bowel fistula formation when NPWT was placed over unprotected intestines, and rare instances of toxic shock syndrome associated with NPWT dressings [19, 20]. These are usually linked to user error or contraindicated usage (for instance, NPWT placed over untreated infection or necrotic tissue can trap bacteria, or over a vascular graft can cause erosion). Thus, all NPWT systems mandate careful patient selection and adherence to contraindications. Manufacturers have incorporated some safety features (alarms, pressure sensors) in pump units; for example, the VAC will alarm if pressures aren't being maintained (signaling a leak or blockage). The single-use devices lack alarms, so patient education is needed to recognize loss of seal (e.g. if the dressing visually collapses or exudate leaks). With proper training and protocol, NPWT can be applied very safely. Publications have not identified any one system as safer than another – most adverse events relate to the therapy modality itself rather than a specific brand. One practical point is that gauze NPWT might pose less risk of retained foreign material than foam (as foam can fragment if not removed carefully), but this is mitigated by counting foam pieces and newer foam with X-ray detectable threads.

In summary, a variety of NPWT systems are available, and clinical outcomes are broadly similar across systems, provided the NPWT is appropriately applied. Choice of system may depend on wound type (foam vs gauze), care setting (hospital vs home, favoring smaller devices for the latter), and cost/access considerations. The continued innovation in NPWT devices – such as smarter pumps with feedback control, or hybrid dressings that incorporate NPWT with biomaterials – promises to further improve the versatility and patient-friendliness of this therapy.

Summary and Conclusions

NPWT has established itself as a major advancement in the management of surgical wounds and other difficult-to-heal wounds. Through the orchestrated mechanisms of macrodeformation, microdeformation, fluid removal, and wound protection, NPWT creates almost a perfect environment for healing, which is not possible for traditional dressing. [4, 5]. The clinical evidence base, once limited to case series and small trials, has grown substantially. High-level evidence now supports NPWT's efficacy in multiple domains: it significantly improves healing rates in chronic wounds (especially diabetic foot ulcers) and significantly reduces infection and seroma complications in high-risk surgical incisions [5, 6]. These benefits ultimately translate into better patient outcomes – faster recovery, fewer return trips to the operating room, and possibly improved limb salvage in diabetics. Patients treated with NPWT often report positive experiences of seeing their wound condition improve rapidly (with the caveat of some inconvenience of carrying a pump). Surgeon and wound-care specialist experience over the past decades has expanded appropriate indications for NPWT, which now range from open abdomen management to securing skin grafts and beyond [8].

While NPWT is a powerful tool, it is not a substitute for good surgical practice but rather a complement to it. Proper wound bed preparation (debridement of necrotic tissue, infection control with antibiotics if needed, revascularization of ischemic tissue) is essential – NPWT works best on a clean, adequately perfused wound bed. Additionally, the therapy must be applied correctly: an air-tight seal, appropriate pressure level and mode, and regular monitoring. When these conditions are met, complications are rare. Clinicians must remain vigilant for potential issues like bleeding (especially in patients on anticoagulants or with wounds near blood vessels) and must promptly address any signs of infection that might develop under the dressing (fever, unexpected drainage). Most guidelines recommend not to leave an NPWT dressing in place for more than ~2 days without inspection of the wound, to strike a balance between maintaining a stable environment and catching any problems early [8].

In comparing NPWT with standard care, one should also consider patient quality of life. Traditional wound care might involve multiple dressing changes per day with associated pain and inconvenience. NPWT's ability to extend dressing change intervals to 2–3 days (or more for single-use devices) can significantly improve patient comfort and ease nursing burdens [8]. Many patients can even be discharged sooner with NPWT devices managing their wounds at home, which is a positive outcome both economically and for patient satisfaction. From a healthcare systems perspective, NPWT has an upfront cost but can lead to downstream savings by preventing costly complications and promoting faster healing. The cost-effectiveness has been demonstrated in scenarios like orthopedic surgery and abdominal surgery, where avoiding one deep infection offsets many NPWT dressings' expense [10].

Looking ahead, future directions for NPWT include further refinement of technique and exploring new combinations. Research is ongoing into the optimal negative pressure level and cycle (for instance, alternating pressure levels or periodic pauses may enhance mechanotransduction further). The synergy of NPWT with instillation therapy (NPWTi) is being actively explored for managing biofilm-laden wounds; early results show improved clearance of bacteria and healing in wounds that failed standard NPWT, indicating a promising avenue for refractory infections [17]. Another area of interest is pairing NPWT with adjunctive therapies – for example, instilling growth factors, stem cells, or antibiotics into a wound under NPWT to directly deliver therapies while NPWT prepares the bed. Additionally, biomaterials such as cytokine-binding meshes or oxygen-infusing layers could be integrated into NPWT foam to target specific barriers to healing. These advanced concepts remain experimental but could define the next generation of “active” NPWT dressings.

In conclusion, NPWT has transitioned from an innovative idea to an indispensable component of wound management in surgery. Its mechanisms of action are well-elucidated and showcase how mechanical forces can beneficially influence biology. Clinically, NPWT improves outcomes in a variety of challenging situations – from large traumatic wounds to high-risk surgical incisions – and its use has expanded across specialties. Numerous NPWT systems are now available, and evidence indicates that when used appropriately, they all can achieve effective results, giving clinicians flexibility to choose based on context. The keys to success with NPWT are proper patient selection, integration with standard surgical care, and vigilant monitoring. When these are in place, NPWT can dramatically tilt the healing trajectory in the patient’s favor. Ongoing innovations and research will likely further enhance NPWT’s effectiveness and ease-of-use, cementing its role in improving surgical wound healing and patients’ lives.

AUTHOR’S CONTRIBUTIONS

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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