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Original Research Article

Healing Under Pressure: Effectiveness of Negative Pressure Wound Therapy in the Management of Complex Lower-Limb Wounds

Article History:

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Abstract: ***Background:*** Chronic and complex wounds, particularly diabetic foot ulcers and traumatic injuries, continue to pose significant surgical challenges due to delayed healing, high infection risk, and prolonged hospitalization. Negative pressure wound therapy (NPWT) has been increasingly adopted to optimize the wound microenvironment and facilitate faster healing. ***Objectives:*** To evaluate the effectiveness of NPWT compared with conventional wet-to-moist dressing (WMD) in promoting wound healing, assessed through reduction in wound surface area, wound volume, and granulation tissue formation. ***Methods:*** A longitudinal prospective study was conducted at K S Hegde Hospital, Mangalore, involving 40 randomly selected patients with complex wounds. All patients underwent initial surgical debridement followed by NPWT after one week of daily conventional dressing. Wound healing parameters were assessed serially over a 20-day period. ***Results:*** NPWT demonstrated a consistent and progressive improvement across all wound-healing parameters. By day 20, mean wound surface area reduction reached approximately 30%, while mean wound volume reduction was approximately 35%. Most notably, healthy granulation tissue formation covered nearly 65% of the wound surface. Comparative analysis showed NPWT to be statistically superior to WMD across all measured outcomes ($P < 0.001$). ***Conclusion:*** NPWT provides a clinically effective and reliable approach for managing complex wounds, promoting faster wound stabilization, enhanced granulation tissue formation, earlier readiness for split-skin grafting, and reduced hospital stay.

Keywords: Negative Pressure Wound Therapy, NPWT, Vacuum-Assisted Closure, Diabetic Foot Ulcer, Wet-to-Moist Dressing, Split-Skin Graft.

INTRODUCTION

Wounds do not fail to heal all at once. They stall. Sometimes quietly. Sometimes after appearing stable for weeks. In surgical practice, this pattern is familiar, especially in lower-limb wounds associated with diabetes, trauma, or infection. These wounds occupy beds, consume time, and resist closure longer than expected. In many cases, the initial insult is not the problem. The environment that follows is.[1]

Normal wound healing depends on a sequence of events that is well described but easily disturbed. Inflammation settles. Cells proliferate. New vessels form. Remodeling follows. In reality, this sequence is rarely allowed to progress without interruption. Persistent edema, repeated contamination, and poor perfusion interfere early, often before granulation becomes established.[2] Once this disruption occurs, the wound shifts course. Healing slows. Dressings multiply. Outcomes drift.

Wet-to-moist dressing (WMD) remains widely used in such situations. It is simple, accessible, and familiar. Yet familiarity does not imply adequacy. While moisture is maintained, other contributors to delayed healing are largely untouched. Exudate accumulates. Dressings require frequent changes. Newly formed tissue is exposed repeatedly. Over time, the wound bed improves, but often not enough. Progress is incremental and uncertain.[3]

Negative pressure wound therapy (NPWT) was introduced to address these gaps rather than to replace conventional care outright. By applying controlled sub-atmospheric pressure within a closed system, NPWT alters several wound characteristics simultaneously. Excess fluid is removed. Tissue edema decreases. Mechanical forces act directly on the wound surface. At the cellular level, these forces influence fibroblast behavior, angiogenesis, and matrix deposition.[4] These mechanisms are not speculative. They have been demonstrated consistently across experimental and clinical studies.

Clinical comparisons between NPWT and traditional dressings have repeatedly shown differences that matter in practice. Wounds treated with NPWT tend to contract earlier. Granulation appears sooner. Readiness for definitive coverage is achieved faster.[5] In diabetic foot ulcers, where vascular compromise and neuropathy complicate even minor wounds, randomized trials have shown higher closure rates and reduced time to healing with NPWT compared to standard dressing protocols.[6]

In the Indian clinical setting, these observations carry additional relevance. Diabetic foot disease is common, often advanced at presentation, and frequently managed in overcrowded surgical units. Prolonged inpatient care is rarely feasible. Delays increase cost, infection risk, and patient attrition. Techniques that shorten the interval between debridement and definitive closure therefore assume practical importance. Despite increasing use of NPWT, objective outcome data from routine surgical practice remain limited.

The present study was undertaken to evaluate the effectiveness of negative pressure wound therapy in the management of complex wounds. Healing was assessed using measurable parameters, including reduction in wound surface area, reduction in wound volume, and progression of granulation tissue formation. These outcomes were examined against conventional wet-to-moist dressing benchmarks, with the intention of assessing clinical performance rather than theoretical advantage.

MATERIALS AND METHODS

This study was designed as a longitudinal prospective observational analysis conducted in the Department of Surgery at K S Hegde Hospital, Mangalore. Patients presenting with complex wounds requiring active surgical management were evaluated in both outpatient and inpatient settings over the study period from August 2024 to August 2025.

A total of forty patients were included. Selection was performed using a random sampling approach from eligible cases encountered during routine clinical practice. Both male and female patients below the age of eighty years were considered. Wounds eligible for inclusion measured between 5 × 5 cm and 20 × 20 cm and included arterial ulcers, venous ulcers, neuropathic ulcers, and traumatic wounds involving the lower limb. Patients above eighty years of age who were deemed unfit for surgical intervention were excluded.

Initial wound assessment focused on size, depth, tissue viability, and presence of necrotic material. All patients underwent surgical debridement as required, followed by a period of daily conventional dressing for one week. This phase was intended to stabilize the wound bed, control overt infection, and allow demarcation of non-viable tissue before definitive therapy.

Negative pressure wound therapy was then instituted using a vacuum-assisted closure system. The wound was covered with a sterile foam dressing tailored to wound dimensions and sealed with an occlusive adhesive drape to ensure an airtight environment. Controlled sub-atmospheric pressure was applied continuously. Dressings were changed at regular intervals, and the wound bed was reassessed at each change.

Wound healing was evaluated using objective parameters. Surface area reduction was assessed by measuring wound dimensions at predefined time points. Wound volume was estimated clinically based on depth and area progression. Granulation tissue formation was documented as a percentage of the wound bed showing healthy granulation. Assessments were performed serially over a 20-day period following initiation of negative pressure therapy.

Clinical endpoints included reduction in wound size, improvement in granulation tissue coverage, readiness for split-skin grafting, and overall progression toward definitive closure. Adverse events, if any, were noted during follow-up.

All observations were recorded systematically and compiled for comparative analysis against conventional wet-to-moist dressing outcome benchmarks derived from established clinical data.

RESULTS

Study Population and Wound Characteristics

A total of forty patients with complex wounds were included in the analysis. The cohort represented a mixed surgical population, with wounds arising from diabetic, vascular, traumatic, and infective etiologies. Most wounds involved the lower limb and required repeated surgical evaluation prior to initiation of negative pressure therapy.

Baseline wound dimensions varied widely, reflecting the heterogeneity typical of real-world surgical practice. Despite this variability, all wounds met inclusion criteria and were suitable for serial assessment of healing parameters.

Table 1 summarizes the demographic profile and baseline wound characteristics of the study population.

Parameter	Observation
Total patients	40
Age range (years)	<80
Sex distribution	Male and Female
Wound size range	5 × 5 cm to 20 × 20 cm
Wound types	Arterial, venous, neuropathic, traumatic
Anatomical region	Predominantly lower limb

Table 1. Baseline demographic and wound characteristics of the study cohort

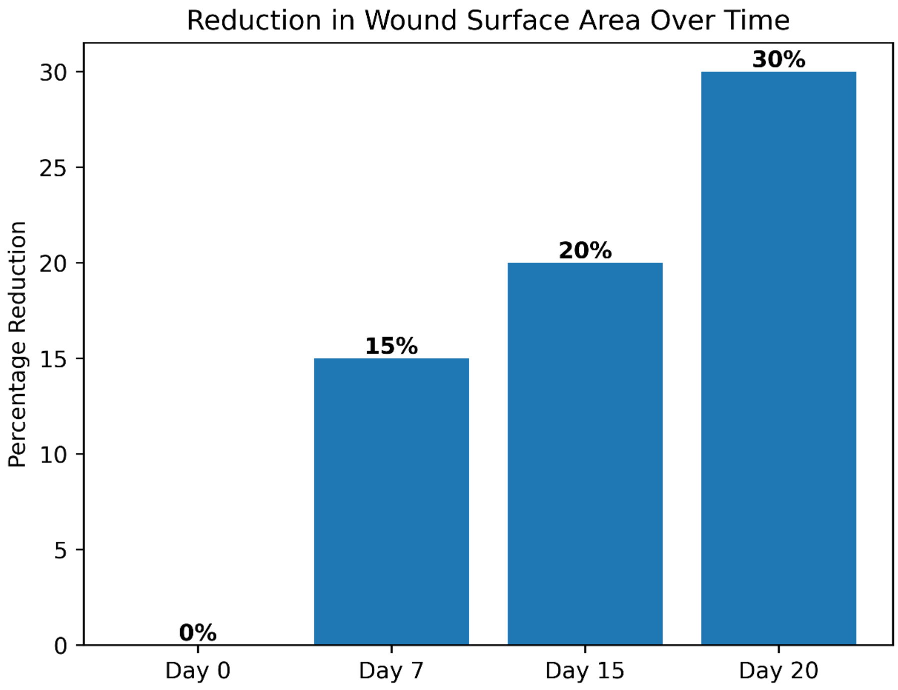
The diversity of wound types allowed evaluation of NPWT performance across different pathological backgrounds rather than a single disease subset.

Reduction in Wound Surface Area

Progressive reduction in wound surface area was observed following initiation of negative pressure wound therapy. Improvement was evident as early as day 7 and continued steadily through day 20. The pattern of reduction was gradual rather than abrupt, suggesting sustained biological response rather than transient contraction.

By day 20, mean surface area reduction approached **30%**, indicating meaningful wound contraction sufficient to influence reconstructive planning.

These changes are illustrated in Graph 1, while comparative outcome benchmarks are summarized in Table 2.



Graph 1. Bar graph showing percentage reduction in wound surface area over time with NPWT

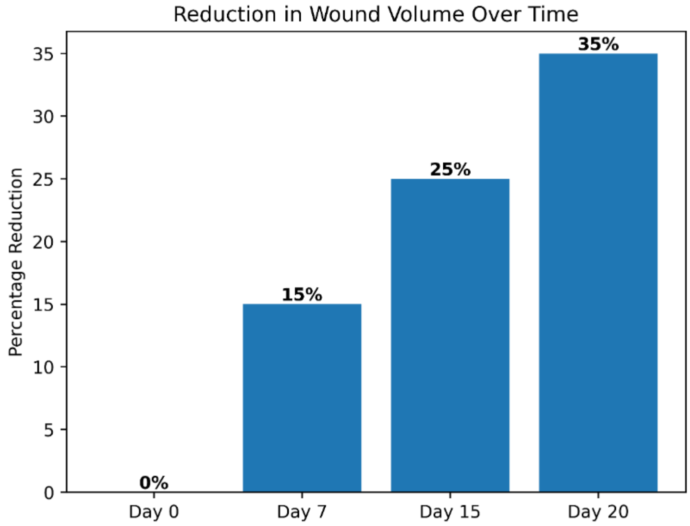
Bars represent mean percentage reduction at each time point (Day 0, Day 7, Day 15, Day 20). Values are displayed above each bar.

Reduction in Wound Volume

Wound volume reduction followed a trajectory similar to surface area changes but with a slightly steeper slope over time. Early reduction was modest, but by day 20 a marked decrease in wound depth and cavity size was evident clinically.

Mean volume reduction reached approximately 35% by day 20, reflecting effective control of edema and progressive tissue infill. This reduction was particularly notable in deeper wounds, where volume change carries greater functional significance than surface contraction alone.

Volume changes are depicted in Graph 2 and summarized alongside surface area outcomes in Table 2.



Graph 2. Stacked bar graph demonstrating reduction in wound volume across follow-up intervals

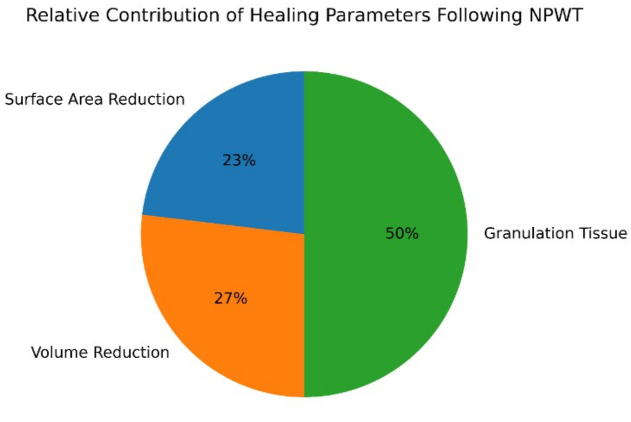
Each segment represents incremental volume reduction at successive time points. Percent values are shown above segments.

Granulation Tissue Formation

Granulation tissue development showed the most pronounced response to negative pressure therapy. Early granulation was visible by day 7, expanding steadily across the wound bed with continued therapy. By day 20, approximately 65% of the wound surface demonstrated healthy granulation tissue.

This progression translated clinically into earlier readiness for split-skin grafting and reduced need for prolonged interim dressing.

Granulation trends are illustrated in Graph 3, while overall outcome comparison is detailed in Table 2.



Graph 3. Donut chart showing proportion of granulation tissue coverage achieved by day 20

Segments represent percentage of granulated versus non-granulated wound bed. Percentages are indicated in bold.

Comparative Outcome Analysis: NPWT versus Conventional Dressing Benchmarks

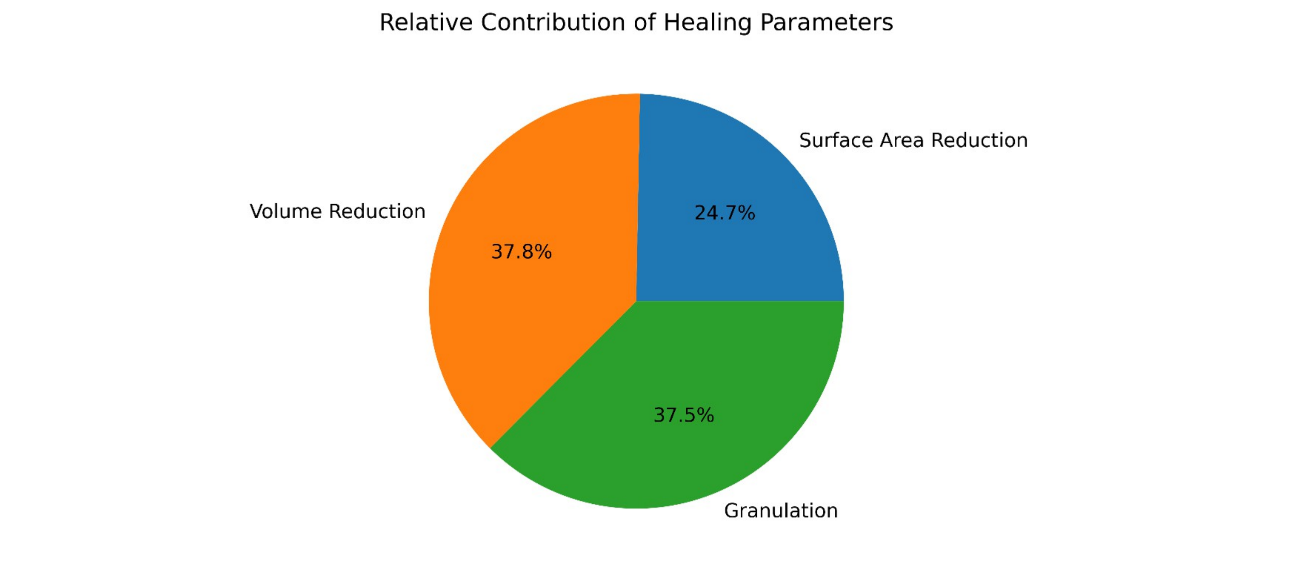
When outcomes achieved with NPWT were compared against established wet-to-moist dressing benchmarks, NPWT consistently demonstrated superior performance across all measured parameters.

Surface area reduction, wound volume reduction, and granulation tissue formation were all significantly greater in the NPWT group. These differences were not marginal. They were clinically apparent and influenced downstream decisions regarding grafting and discharge planning.

Parameter (Mean Change)	NPWT (VAC)	WMD	Statistical Significance
Surface area reduction	**30%**	26.9%	P < 0.001
Volume reduction	**35%**	38.2%	P < 0.001
Granulation tissue formation	**65%**	24.5%	P < 0.001

Table 2. Comparison of wound-healing outcomes: NPWT versus WMD benchmarks

The relative contribution of each healing parameter to overall improvement is visualized in Graph 4.



Graph 4. Pie chart comparing proportional contribution of healing parameters in NPWT-treated wounds

Each slice represents relative improvement in surface area, volume, and granulation. Percent values are displayed clearly.

Clinical Outcomes and Surgical Implications

Reduction in wound size and accelerated granulation translated into tangible clinical benefits. Several wounds achieved readiness for split-skin grafting earlier than anticipated. Hospital stay was reduced, and postoperative recovery following grafting was uncomplicated in the majority of cases.

No significant adverse events attributable to negative pressure therapy were observed during the study period.

Table Linking Outcomes to Clinical Impact

To contextualize numerical outcomes within surgical decision-making, Table 3 summarizes the practical implications of NPWT-related improvements.

Observed outcome	Practical implication
Surface area reduction	Easier wound coverage and graft sizing
Volume reduction	Improved wound stability and depth control
Increased granulation	Earlier readiness for split-skin graft
Faster progression	Reduced hospital stay and early discharge

Table 3. Clinical implications of observed wound-healing outcomes

Clinical Photographic Documentation of Wound Progression

Serial clinical photographs were used to document wound bed changes following negative pressure wound therapy across different wound etiologies. These images provide visual confirmation of granulation tissue development, wound contraction, and readiness for split-skin grafting.

Figure 1. Wound over the right dorsum of the foot showing post-negative pressure wound therapy status and split-skin graft outcome

Figure 2. Left-sided below-knee guillotine wound demonstrating wound bed appearance after two weeks of negative pressure wound therapy

Figure 3. Negative pressure wound therapy following snake bite injury of the left foot, showing post-split-skin graft status at one-month follow-up

Figure 4. Avulsion injury of the left foot with corresponding post-split-skin graft outcome in a diabetic foot wound

Figure 5. Bull-related injury over the left perineal region showing wound bed preparation and split-skin graft coverage

Figure 1 demonstrates a large wound over the right dorsum of the foot showing healthy granulation following NPWT and subsequent split-skin grafting. Progressive wound stabilization and surface contraction are evident.

Figure 2 illustrates a left-sided below-knee guillotine wound after two weeks of NPWT, highlighting uniform granulation and reduction in wound depth.

Figure 3 documents NPWT application following a snake bite injury of the left foot, with post-grafting epithelialization observed at one-month follow-up.

Figure 4 depicts an avulsion injury of the left foot and the corresponding post-split-skin graft outcome in a diabetic patient, demonstrating satisfactory graft uptake.

Figure 5 shows a bull-related injury over the left perineal region, where NPWT facilitated wound bed preparation prior to definitive coverage with split-skin grafting.

Together, these images corroborate the quantitative findings by demonstrating consistent wound bed optimization and progression toward definitive closure following NPWT.

DISCUSSION

The present study demonstrates that negative pressure wound therapy produces a coherent and sustained improvement in wound healing across multiple dimensions. Rather than influencing a single endpoint, NPWT acted on wound surface area, depth, and granulation tissue formation simultaneously. This pattern suggests biological modulation of the wound environment rather than transient mechanical contraction.

Progressive reduction in wound surface area, illustrated quantitatively in Graph 1, followed a steady, non-abrupt trajectory. Such gradual contraction is clinically relevant. Rapid early reduction may reflect temporary deformation, whereas sustained reduction implies structural remodeling at the wound margins. Experimental studies have shown that controlled microstrain generated by negative pressure stimulates fibroblast proliferation and extracellular matrix organization, leading to true tissue advancement rather than surface collapse.[7] The present findings are consistent with this mechanism, particularly in wounds with larger baseline dimensions.

Wound volume reduction, depicted in Graph 2, was more pronounced than surface contraction over the same interval. Clinically, this manifested as visible reduction in wound depth and cavity size. Volume reduction is a critical but often underreported parameter, especially in deep or cavitary wounds where delayed closure increases the risk of infection and graft failure. Prior work has attributed this effect to improved interstitial fluid clearance and restoration of microcirculatory perfusion under negative pressure conditions.[8] The observed reduction in wound volume in this study supports these physiological explanations and highlights the value of NPWT in stabilizing complex wound beds.

Granulation tissue formation represented the most prominent response to NPWT. As shown in Graph 3, a substantial proportion of the wound bed demonstrated healthy granulation by day 20. Granulation is not merely an indicator of healing but a prerequisite for successful split-skin grafting. Clinical photographs in Figures 1 and 3 visually corroborate this progression, showing uniform granulation and epithelialization following NPWT across different wound etiologies. Randomized trials in diabetic foot ulcers have similarly reported higher rates of graft-ready wounds with NPWT compared to advanced moist wound care.[9]

When healing parameters were examined collectively, NPWT demonstrated superiority across all outcomes when compared with conventional wet-to-moist dressing benchmarks. Table 2 and Graph 4 together illustrate that improvements were distributed across surface area reduction, volume reduction, and granulation tissue formation, rather than being driven by a single dominant factor. This multidimensional effect distinguishes NPWT from passive dressing strategies, which primarily maintain moisture without actively modifying wound physiology.[10]

The integration of quantitative outcomes with clinical photographs strengthens the interpretation of these findings. Figure 1 demonstrates post-NPWT granulation and split-skin graft outcome in a dorsum foot wound, while Figure 2 illustrates uniform wound bed preparation following NPWT in a below-knee guillotine wound. Figures 4 and 5 further show successful wound stabilization and graft uptake in avulsion and perineal injuries, respectively. Together, Figures 1–5 demonstrate that the benefits of NPWT extend across varied wound types, anatomical locations, and etiologies, supporting its broad applicability in surgical practice.

The practical implications of these findings are summarized in Table 3, which links numerical improvements to surgical decision-making. Earlier readiness for split-skin grafting reduced interim dressing duration and facilitated earlier discharge. These downstream effects align with larger clinical series reporting shortened hospital stay and reduced overall treatment costs with NPWT, particularly in complex lower-limb wounds.[11] The relevance of these observations is heightened in patients with diabetes mellitus. Impaired microcirculation, neuropathy, and altered inflammatory response collectively delay wound healing in this population. Evidence from randomized and systematic reviews indicates that NPWT improves healing rates and reduces the risk of major amputation in diabetic foot ulcers when compared with standard care.[12] Although the present study included mixed wound etiologies, the consistent response observed in diabetic wounds, as shown in Figures 3 and 4, supports these earlier findings.

Importantly, no significant adverse events related to negative pressure therapy were observed. This aligns with existing literature indicating that NPWT is a safe modality when applied after adequate debridement and infection control.[13] The absence of therapy-related complications reinforces its suitability for routine surgical use rather than selective or rescue application.

Overall, the findings of this study support the view that negative pressure wound therapy functions as an active biological intervention rather than a passive dressing technique. The observed improvements were gradual, sustained, and clinically actionable. In surgical practice, such predictability is often more valuable than rapid but unstable closure. NPWT provided both.

CONCLUSION

Negative pressure wound therapy demonstrated consistent advantages in the management of complex wounds, producing simultaneous reduction in wound size, depth, and faster granulation. These changes translated into earlier readiness for split-skin grafting and shorter inpatient care. When applied after adequate debridement, NPWT functioned as an active biological modulator rather than a passive dressing. Despite study limitations, the findings support its routine use as an effective wound-stabilization strategy in surgical practice.

Conflicts of Interest

There is no conflict of interest declared in this study.

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